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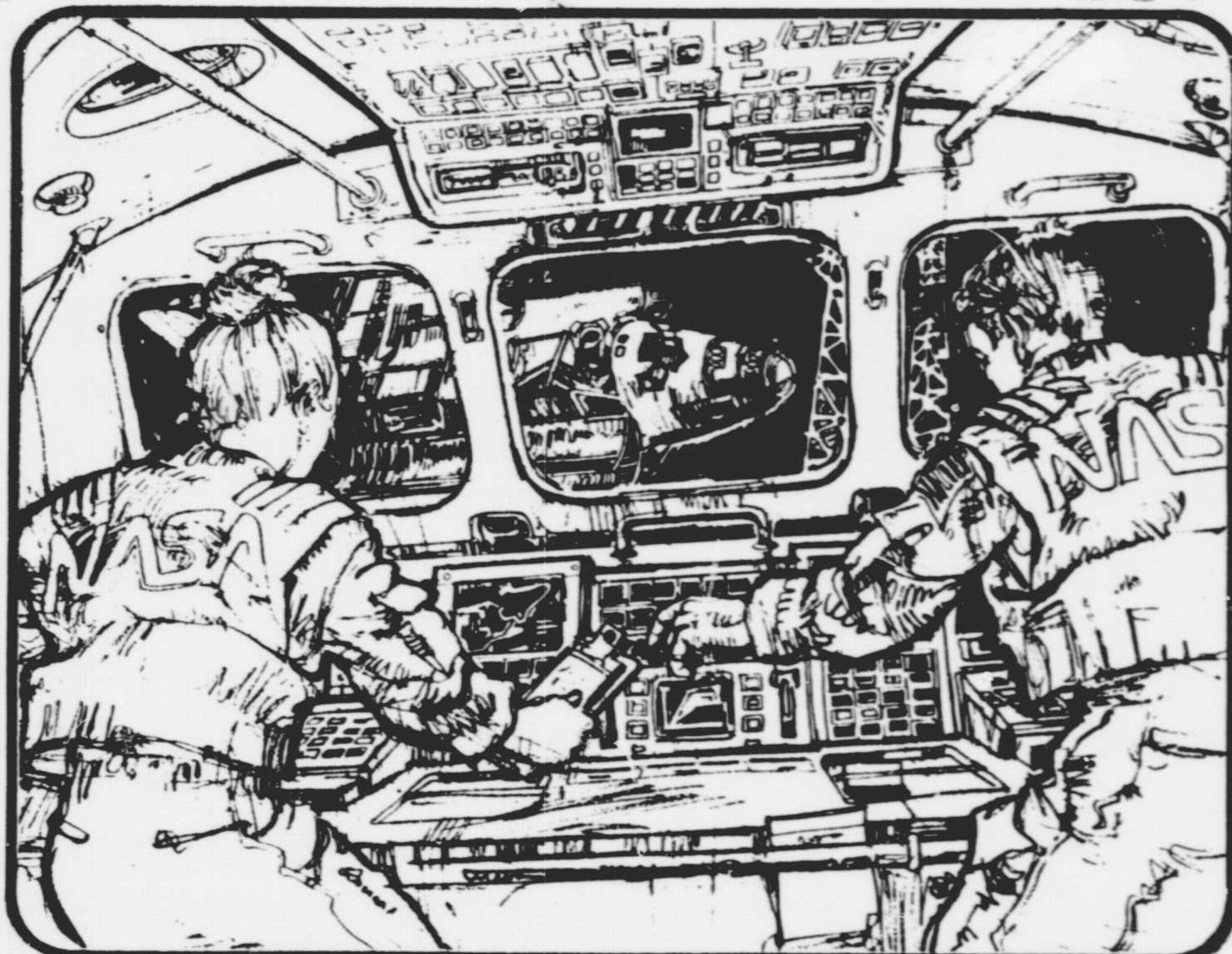
Mid-Term Briefing
D180-27305-1
November 18, 1982



Space Station Needs, Attributes, and Architectural Option Study

Space Station

NASA 86-113 BOEING

Space Station Needs, Attributes, and Architectural Options Study

Midterm Briefing

November 18, 1982

Space Systems Division

Boeing Aerospace Company

Seattle, Washington

TEAM ORGANIZATION

The study team organization and its relationship to the Boeing Aerospace Company Management are diagrammed on the facing page.

Space Station

Team Organization

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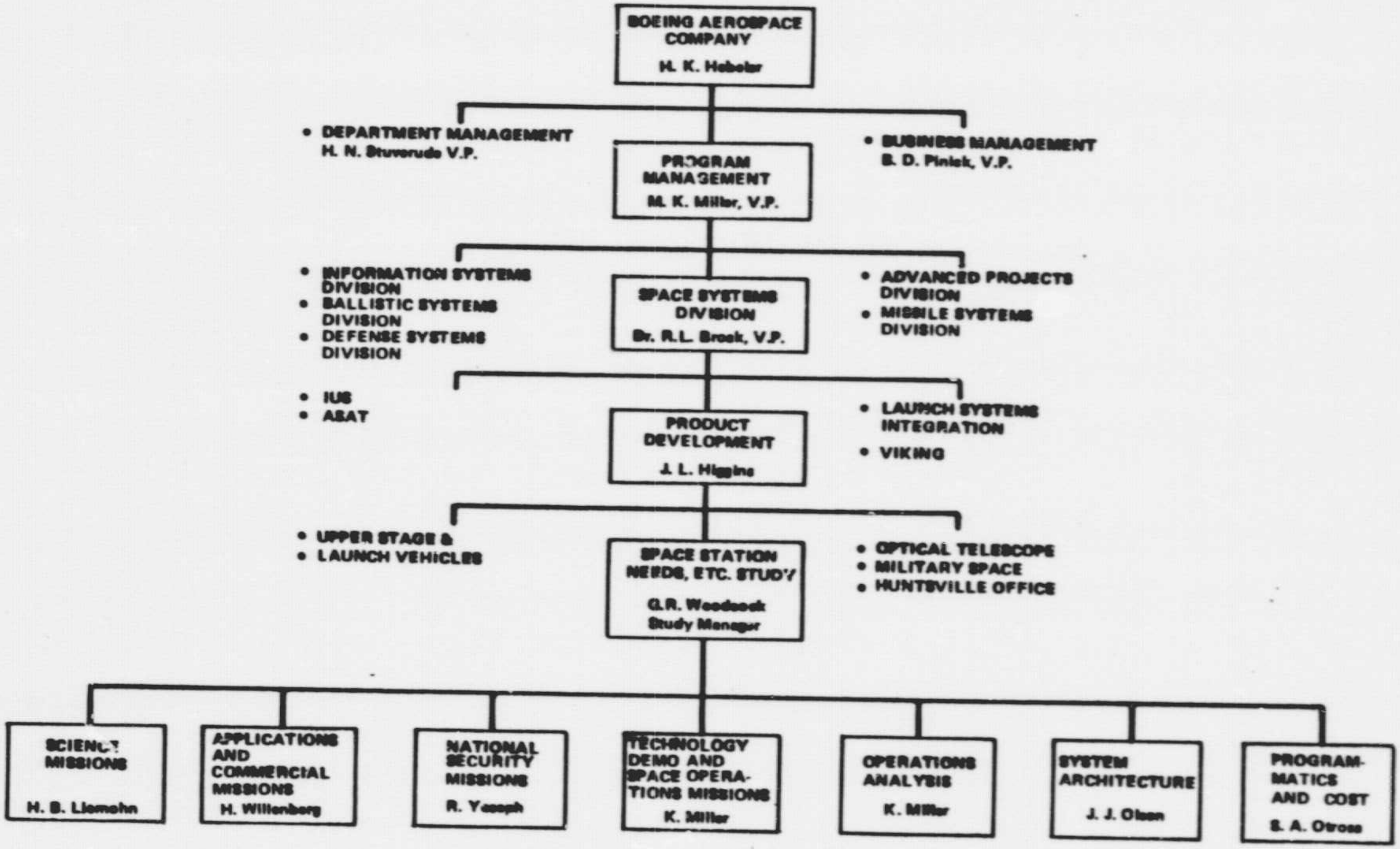

Agenda

Executive Summary	Gordon Woodcock
Science and Applications Missions	Dr. Harold Liemohn
Commercial Missions	Dr. Harvey Willenberg
Technology Demonstration Missions	Keith Miller
Space Operations Missions	Keith Miller
Topics of Interest	Gordon Woodcock
Concluding Remarks	J. L. Higgins
National Security Missions (Classified Addendum)	Bob Yoseph

Executive Summary

STUDY SCHEDULE

The study schedule status is shown on the facing page. The period of technical work is approximately half complete. Roughly one-third of the study resources have been spent.

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Study Schedule

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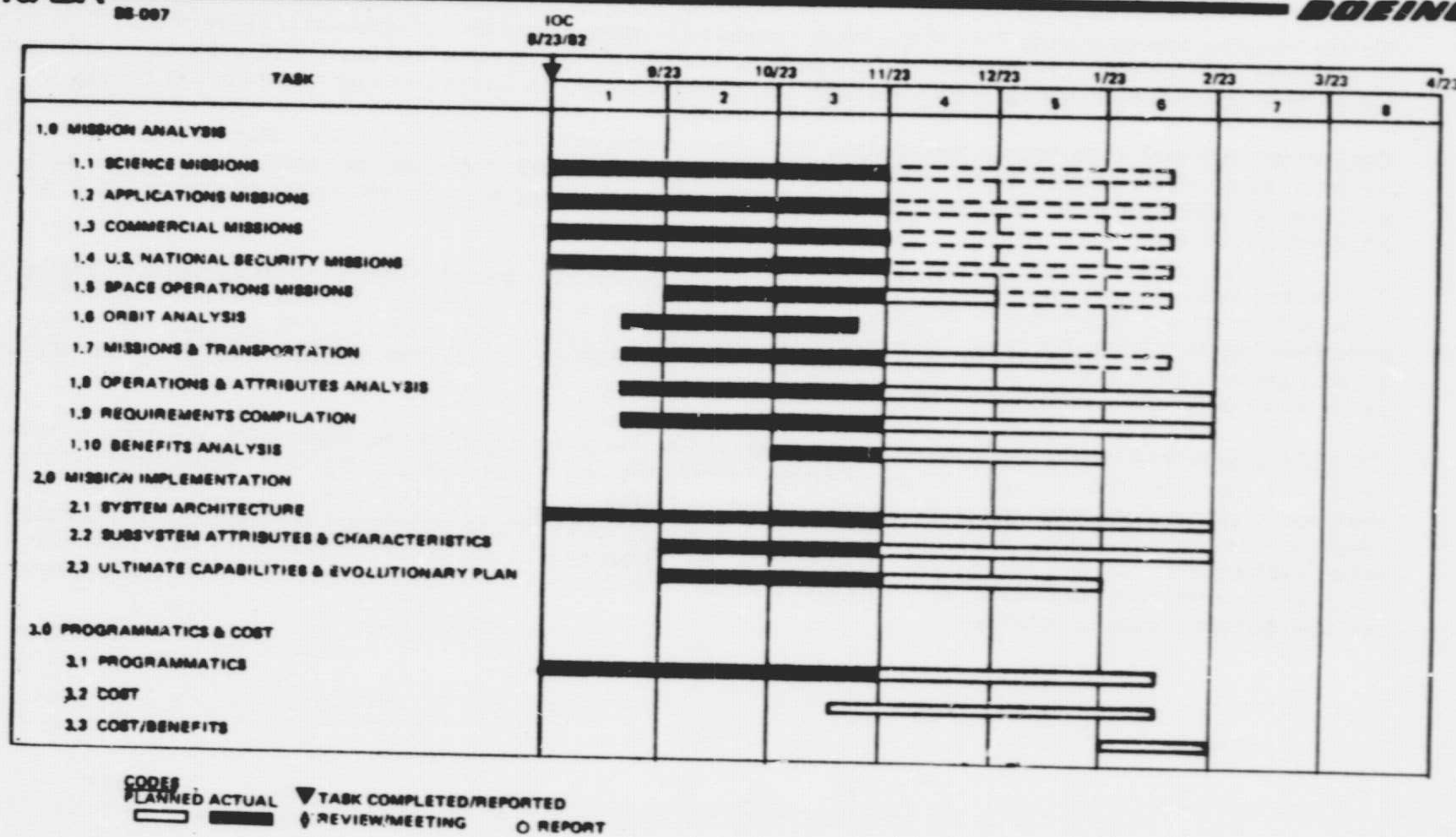

STUDY APPROACH AND RATIONALE

We are investing approximately 75% of the study resources in mission analysis activities with the remaining 25% going to attributes and architectural options and programmatics. Somewhat greater emphasis than originally planned has been placed on mission analysis in view of related activities on system architecture being carried out at Boeing.

Our overall approach is to survey and analyze user needs in conjunction with analysis of other factors influencing potential space station architectures, in order to derive a set of needed attributes and requirements. In parallel, we will develop initial concepts and options, subject them to trades evaluated against criteria, and derive a set of architectural options.

The overall mission analysis approach recognizes that the inputs from potential users we obtain without paying for them will be generally limited to telephone contacts and some letter responses. In order to develop a depth of understanding of mission needs we have augmented our broad scope of user contacts with specific subcontracts in several areas. These permit depth of understanding of these specific areas. The remainder of the necessary user needs data can be filled in through inferential logic.

The guiding principles of our study approach are indicated on the lower right. We emphasize understanding of mission needs and how they are reflected in space station attributes and requirements. We will cover all the bases in developing options, attributes and requirements, to ensure that we have not left out important considerations. We will distinguish between permanent presence and permanent manned presence to understand and highlight the benefits of crew involvement. We will understand "desirements" vs. requirements and their costs and benefits, to ensure that accepted requirements have affordable costs and adequate benefits. We will provide specific rationale and logic for our selected architectural options.

Space Station

Study Approach and Rationale

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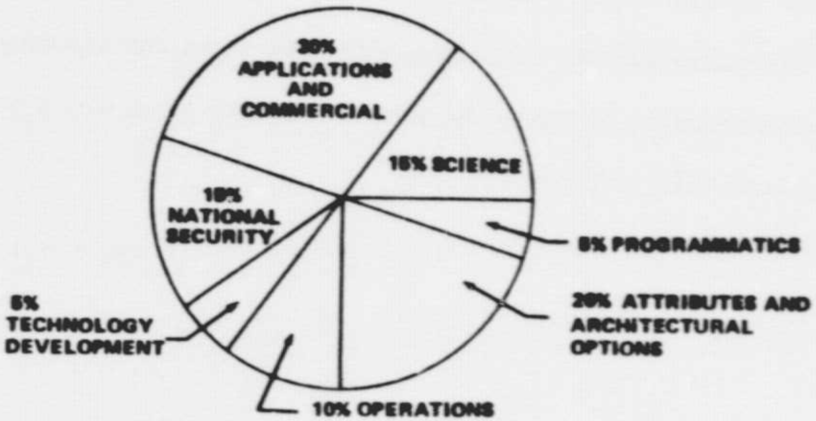
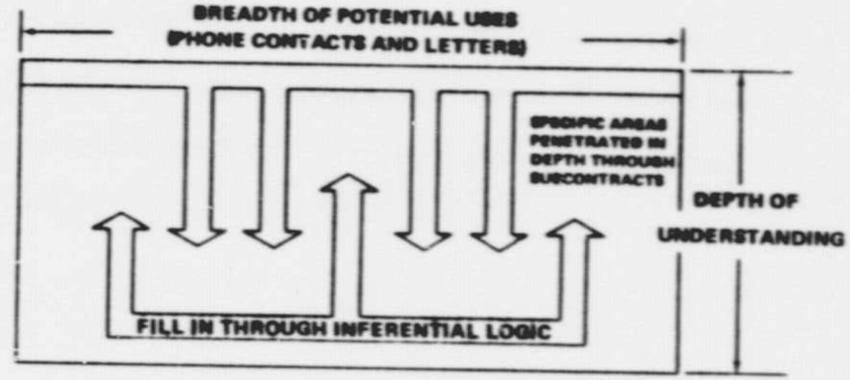
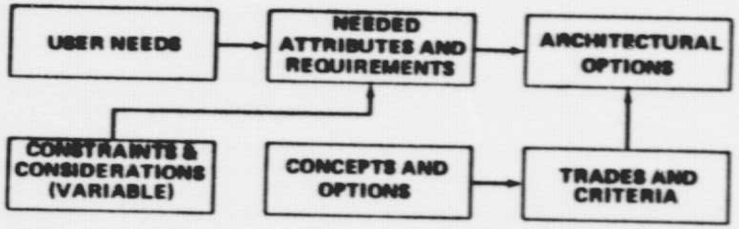
DISTRIBUTION OF EFFORT



OVERALL LOGIC



MISSION NEEDS APPROACH



GUIDING PRINCIPLES

- EMPHASIZE UNDERSTANDING OF MISSION NEEDS
- COVER ALL THE BASES IN DEVELOPING OPTIONS, ATTRIBUTES AND REQUIREMENTS
- DISTINGUISH BETWEEN "PERMANENT PRESENCE" AND "PERMANENT MANNED PRESENCE" – UNDERSTAND BENEFITS OF CREW INVOLVEMENT
- UNDERSTAND "DESIREMENTS" VERSUS REQUIREMENTS
- UNDERSTAND COSTS AND BENEFITS
- PROVIDE SPECIFIC RATIONALE FOP ARCHITECTURAL OPTIONS

SUBCONTRACTS

Our study approach involves the use of subcontractors in certain mission areas to provide expertise and indepth understanding of specific missions. The facing page lists our subcontractors that along with their tasks and selection rationale. Two small subcontracts have been added since the beginning of this study, to cover specific areas where we uncovered important mission areas and expertise not recognized when we began the study.

Space Station

Subcontracts

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	WHO	WHAT	WHY
MISSIONS	ARTHUR D. LITTLE	MATERIALS PROCESSING IN SPACE	• EXPERIENCE WITH MANY INDUSTRIAL CLIENTS • INSTITUTIONAL PERSPECTIVE
	BATTELLE	MATERIALS PROCESSING IN SPACE	• EXPERTISE ON ONE SPECIFIC BIOLOGICAL
	ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN (ERIM)	EARTH OBSERVATION MISSIONS	• BROAD EXPERTISE IN CIVIL AND MILITARY APPLICATIONS • USER ORIENTATION
	MICROGRAVITY RESEARCH ASSOCIATES	MATERIALS PROCESSING IN SPACE	• COMMERCIAL MARKET POTENTIAL IS LARGE • ACQUIRE IN-DEPTH UNDERSTANDING OF NEEDS AND BENEFITS • TYPICAL ENTREPRENEURIAL INVESTMENT COMPANY
	RCA	COMMUNICATIONS SPACECRAFT	• USER ORIENTATION – ESSENTIAL FOR THIS APPLICATION • ACQUIRE IN-DEPTH UNDERSTANDING OF NEEDS AND BENEFITS
	SAI	SPACE SCIENCE	• USER ORIENTATION – SPACE SCIENCE EXPERTISE
SUBSYSTEMS	HAMILTON STANDARD; LIFE SYSTEMS	ENVIRONMENTAL CONTROL AND LIFE SUPPORT EQUIPMENT	• EXPERTISE IN EQUIPMENT CHARACTERISTICS, TECHNICAL RISKS AND COSTS
BENEFITS	ECON	PRICING POLICIES AND ECONOMIC BENEFITS	• EXPERTISE ON NASA COSTS, ECONOMICS AND POLICIES • EXPERTISE ON ECONOMIC METHODOLOGY
ATTRIBUTES	NATIONAL BEHAVIORAL SYSTEMS	CREW ACCOMMODATIONS AND ARCHITECTURAL INFLUENCES	• EXPERTISE ON SOCIAL/PSYCHOLOGICAL FACTORS IN HUMAN PERFORMANCE IN STRESSFUL ENVIRONMENTS

SCIENCE AND APPLICATIONS MISSIONS
WHAT WE ARE LEARNING

We have contacted many users, as indicated on the facing page. As expected, their interest ranges from enthusiasm to hostility. The distribution, however, is more toward enthusiasm than we had expected.

We have identified several important benefits to the manned space station. A mission may be accomplished through acquiring an instrument rather than by acquiring a complete spacecraft. Rough-order-of-magnitude costs analyses indicate that the productivity gain ranges from 2 to 3. We can defer or avoid transportation charges and minimize other overhead costs. We should be able to fly up to three times as many major instruments through space station-space platform operations, compared to conventional spacecraft.

Crew involvement provides several benefits, some that cannot easily be accomplished in any other way. In the long run, the manned space station will make space science more like Earth science with experimenter involvement, and enduring instruments, equipment, and systems benefitting from manned service, maintenance, and troubleshooting.

There are four implications to space station attributes and architecture. First, at least two kinds of laboratories are seen to be needed' an onboard general purpose laboratory with diagnostic tools and one or more returnable laboratory modules to house experiment or investigative systems. Secondly, free flier servicing and formation flying is necessary for some of the missions. Third, the availability of service on demand without the necessity of a shuttle flight is a very important benefit. Finally, long term maintenance, modification, and service of instruments and equipment in space indicates the need for a large shirt-sleeved environment workshop. The avoidance of transportation charges for instruments not currently in use suggests a need for a warehouse facility. Last year, we investigated the utility of the shuttle external tank for these applications and found it to be a very attractive option.

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Science & Applications Missions ... What We're Learning

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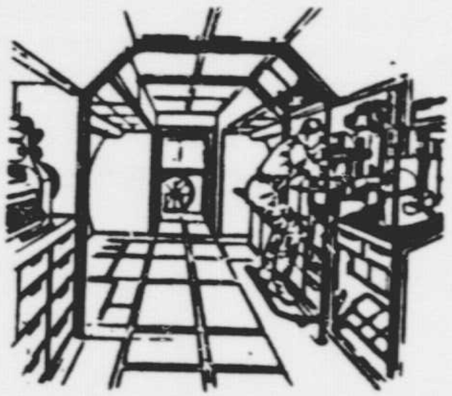

IN ADDITION TO SUBCONTRACTORS, WE HAVE CONTACTED ~ 200 USERS. INTEREST RANGES FROM ENTHUSIASM TO HOSTILITY (AS EXPECTED)

BENEFITS——UTILITY

- INSTRUMENTS VS SPACECRAFT: PRODUCTIVITY FACTOR 2–3
  DEFER/AVOID TRANSPORTATION CHARGES AND DEDICATED SPACECRAFT COST
- CREW INVOLVEMENT
  UNEXPECTED PHENOMENA——INSTRUMENT/OBSERVATION COORDINATION——DATA FUSION——INTERPRETATION——PROTOCOL/PROCEDURE MODIFICATION——THESE BENEFITS ARE QUALITATIVE, i.e., CAN VS CANNOT
- BRINGING SPACE DOWN TO EARTH——MORE PRECISELY, BRINGING EARTH PRACTICES TO SPACE: IN-SITU SCIENCE——SERVICE–MAINTENANCE–TROUBLESHOOTING–INNOVATION

IMPLICATIONS TO SPACE STATION ATTRIBUTES & ARCHITECTURE

- ON-BOARD GENERAL-PURPOSE LABORATORY AS WELL AS RETURNABLE LAB
- FREE-FLYER SERVICING & FORMATION FLYING
- SHIRT-SLEEVE WORKSHOP (ET?)
- WAREHOUSE (ET?)

COMMERCIAL MISSIONS
WHAT WE ARE LEARNING

The space station will serve a servicing need for commercial communications systems. This can stimulate growth in spacecraft size and complexity through new applications and lower cost, resulting in more rapid market growth. However, the communications industry looks to NASA to develop new technologies such as satellite servicing and space construction. A proper blend of NASA technology development and commercial exploitation could provide significant benefits to the U.S. in this market place. The key to rapid economic growth is continued cost reduction and capability improvement.

In microgravity production, we see great cost leverage from the permanent presence in space for the reasons indicated. The various processes have different run times ranging from a few hours to a few months. In a typical production scenario, crew service to the production system at the end of each run would be required. Clearly, for those systems requiring service more frequently than every few months, the benefits of the manned space station are very significant. Further, for research and development in space, having onboard diagnostics capability to support modification of procedures and experimental conditions can greatly speed up process development.

Microgravity Research Associates has made a projection of gallium arsenide annual sales with and without a space station as indicated on the lower left.

Space Station

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Commercial Missions - What We're Learning

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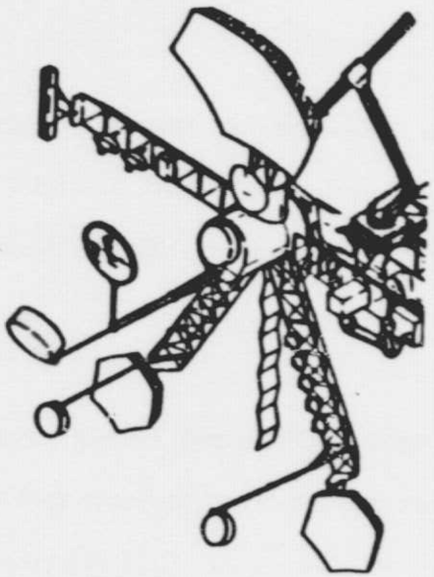
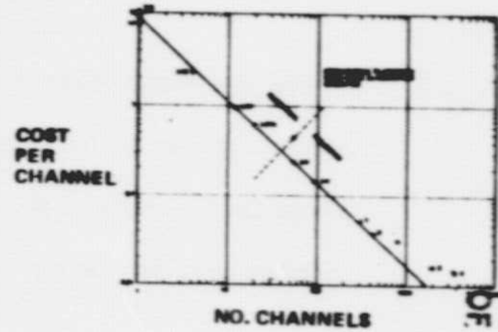


COMMUNICATIONS

WILL STIMULATE GROWTH IN SPACECRAFT SIZE AND COMPLEXITY

- NEW APPLICATIONS
- LOWER COSTS; MORE RAPID GROWTH

COMMUNICATIONS INDUSTRY LOOKS TO NASA TO PIONEER NEW TECHNOLOGY SUCH AS SATELLITE SERVICING; SPACE CONSTRUCTION



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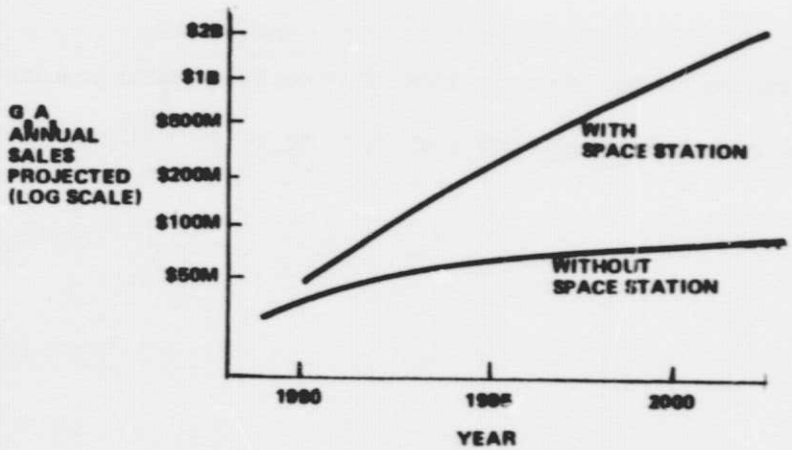


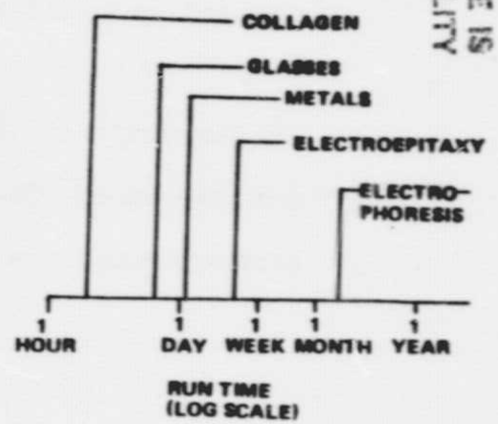
MICROGRAVITY PRODUCTION

GREAT COST LEVERAGE IN PERMANENT PRESENCE

- CONTINUOUS PRODUCTION
- EQUIPMENT STAYS IN SPACE; NO RECURRING TRANSPORT CHARGE
- CREW INVOLVEMENT AS NEEDED

SPEED UP PROCESS DEVELOPMENT

- MODIFY PROCEDURES AND CONDITIONS BASED ON RESULTS
- MUST HAVE DIAGNOSTICS CAPABILITY AT THE STATION



TECHNOLOGY DEVELOPMENT MISSIONS

WHAT WE ARE LEARNING

There are many ideas in this mission area, but relatively few are crystalized. This mission area is a potentially important use of the space station with significant cost savings possibilities. The missions of most significance are those that need to be in space for long durations, requiring extensive support, such as high power. Mission desires and mission cost have in many cases not yet been reconciled.

Examples of high-leverage missions are advanced structural dynamics, control systems and zero-g cryogenics management systems. These technologies have important mission applications and are indicated as needs that require extended experiment time in space with significant support.

The emerging needs for space stations are indicated. These needs are similar to those that we have found in science and applications. Comparison with microgravity research and science uses indicate that use of free fliers will be needed to separate incompatible operations.

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Technology Development Missions - What We Are Learning

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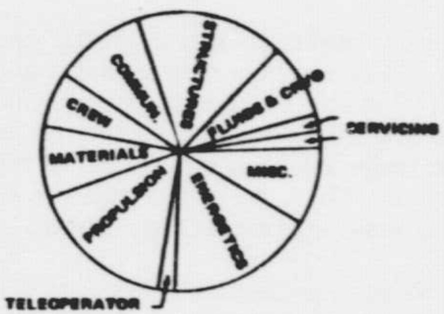

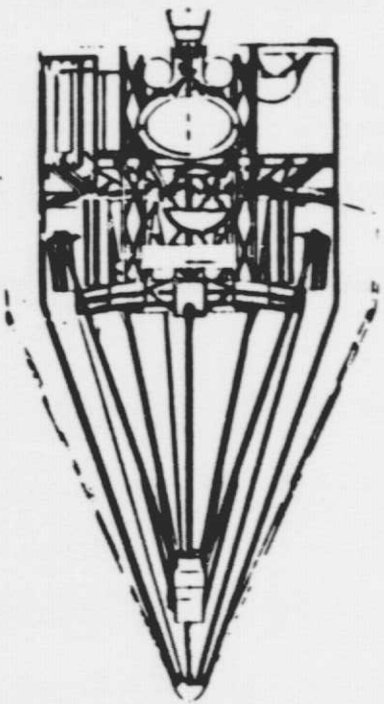

- MANY IDEAS FOR TECHNOLOGY DEVELOPMENT; FEW ARE CRYSTALLIZED
- POTENTIALLY IMPORTANT USE OF SPACE STATION; COST SAVINGS POSSIBILITIES
- LONG-DURATION MISSIONS; THOSE THAT NEED EXTENSIVE SUPPORT, E.G. POWER
- MISSION DESIRES AND MISSION COSTS NOT YET RECONCILED
- EMERGING NEEDS:
  - DEDICATED AND GENERAL-PURPOSE LAB AND COMPUTATIONAL FACILITIES
  - SOME EVA/MMU OPERATIONS
  - DEDICATED MISSION SPECIALISTS (MAY BE A "DESIREMENT")
- TECHNOLOGY DEVELOPMENT IS IMPORTANT TO SPACE STATION EVOLUTION
  - CRYO MANAGEMENT
  - LARGE SPACE STRUCTURES CONTROL AND DYNAMICS
  - OPERATIONS TECHNOLOGY
- POTENTIAL OVERLAPS WITH OTHER MISSION AREAS NEED CONTINUING REVIEW
- CERTAIN INCOMPATIBILITIES WITH MICROGRAVITY AND SCIENCE INDICATE USE OF FREE-FLYERS

NATIONAL SECURITY MISSIONS
WHAT WE ARE LEARNING

There are two scenarios for national security missions: peacetime missions not involving threats to space assets, and crisis/hostility situations involving serious threats. There are three mission classes: (1) technology development and satellite servicing at low inclinations, low altitude. These can be conducted by a civil space station as peace time missions. There are missions involving Earth observation from high inclinations at low alitudes, also restricted to peacetime operations. Finally, there are missions of high national security importance under conflict situations, if the systems are endurable. These must be at high altitude and probably in high inclinations. Thus, there are clusters of missions of low conflict importance, low threats, and others of conflict importance that must operate in high orbits.

There are several issues associated with military uses. One is security of joint operations, if classified missions are conducted on space stations conducting other missions. Several architecture provisions can improve compatibility here, including isolatable command and control areas, secure hangars for handling of classified payloads and secure data and communications.

A high-orbit space station has the potential for great endurance, if it is survivable. It will not run out of fuel or power. It can operate in an autonomous mode without support from the ground for at least six months. The presence of man is important if not essential to this endurability. High altitude orbits raises the issue of cost. In order to understand the cost issue, we are examining all aspects of the system architecture, including crew size as well as transportation support and resupply requirements.

Implications to space station architecture include the necessity for growth to high inclination, high altitude, and high autonomy.

Space Station

National Security Missions - What We Are Learning

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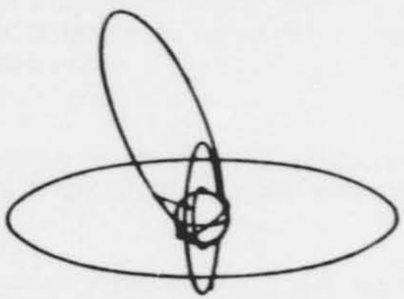
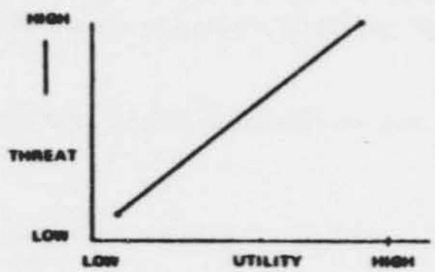
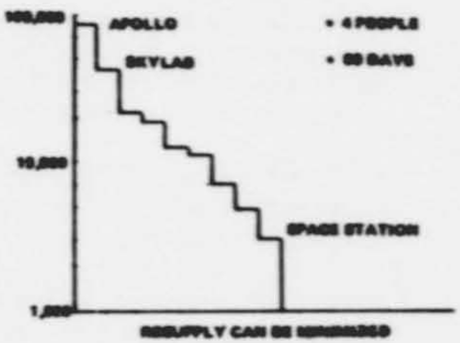
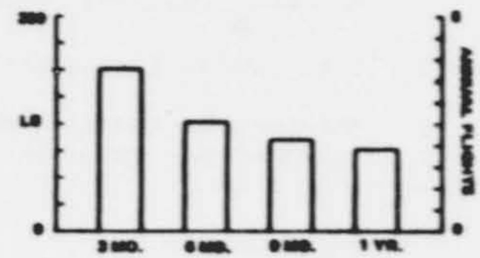
MANY ORBIT OPTIONS





- TWO SCENARIOS: PEACETIME (LOW THREAT); HOSTILITIES (HIGH THREAT)
- THREE MISSION CLASSES:
  - TECHNOLOGY DEVELOPMENT AND SATELLITE SERVICING – LOW INCL, LEO, PEACETIME
  - EARTH OBSERVATION – HIGH INCL, LEO, PEACETIME
  - COMMAND, CONTROL, COMMUNICATIONS AND INTELLIGENCE – HIGH INCL HEO, HIGH VALUE IF ENDURABLE
- ISSUES:
  - SECURITY OF JOINT OPERATIONS
  - SURVIVABILITY ⟺ DISTANCE, REACTION TIME AND COUNTERMEASURES
  - POTENTIAL FOR GREAT ENDURANCE IF SURVIVABLE; PRESENCE OF MAN HELPS
  - COST: NEED TO EXAMINE ALL ASPECTS OF SYSTEM ARCHITECTURE
- IMPLICATIONS: HIGH INCLINATION, ALTITUDE, AND AUTONOMY





• LONG STAY TIME REDUCES COST OF HIGH-ORBIT LOGISTICS

OPERATIONS MISSIONS
WHAT WE KNOW FROM PRIOR WORK

We possess an extensive data base from earlier studies that will be modified and used when current mission requirements are better established. In our earlier studies, we found a great payoff for high-technology space-based upper stages employing aero-assist. If the upper stage is to be space based it must be designed for space turnaround by EVA astronauts with a relatively modest level of effort. This implies design requirements for quick diagnostics of faults and rapid change out of line replaceable units. The application of this high technology goes a long way towards satisfying transportation demand growth without requiring a large transportation fleet.

We identified significant uncertainties in projecting the future of space operations, especially uncertainty in space construction needs. The range of our projections in crew size was much greater than the range of projections in transportation needs.

Operations, research and applications missions have a number of incompatibilities that can be tolerated early in the life of a space station: at a later time we will want to segregate science and operations missions on separate platforms.

Shuttle performance characteristics dictate a station altitude of about of 400 kilometers unless novel mission modes are adopted. This altitude is below that desired for many of the free flier science platforms, posing problems in formation flying that will be discussed later in the briefing. One novel architectural option we are investigating utilizes the teleoperator maneuvering system with a habitable resupply module to resupply and exchange crews in a space station at altitudes the shuttle cannot directly reach.

We concluded that an operational station needs many berthing ports and work areas and must have a mobile crane or mobile remote manipulator system.

Space Station

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Operations Missions - What We Know From Prior Work

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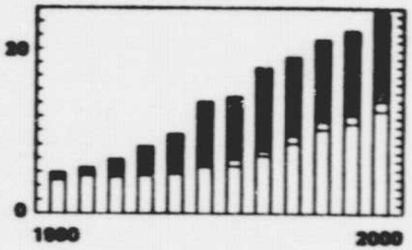
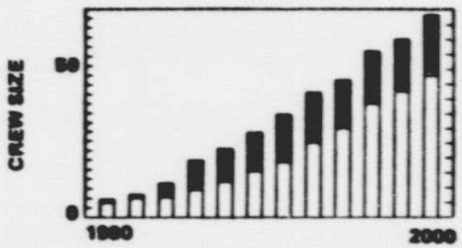
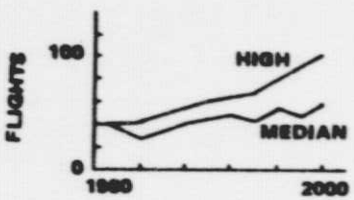
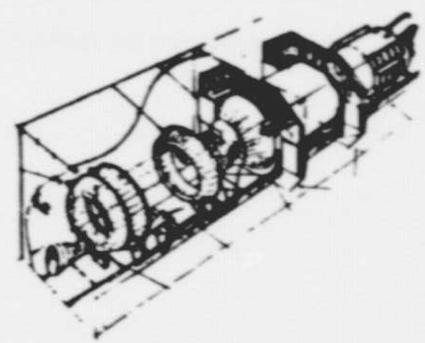


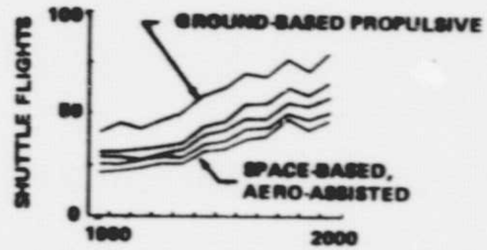




- GREAT PAYOFF FOR HIGH-TECHNOLOGY UPPER STAGE (AEROASSIST) AND SPACE BASING
- UPPER STAGE MUST BE DESIGNED FOR SPACE TURNAROUND
- HIGH TECHNOLOGY SATISFIES DEMAND GROWTH WITHOUT LARGE FLEET
- UNCERTAIN FUTURE OF SPACE CONSTRUCTION IS MAIN SOURCE OF GROWTH REQUIREMENT UNCERTAINTY
- WE WILL WANT TO SEGREGATE SCIENCE AND OPERATIONS MISSIONS ON SEPARATE STATIONS AT SOME POINT ALONG THE GROWTH PATH
- SHUTTLE PERFORMANCE CHARACTERISTICS DICTATE STATION ALTITUDE CIRCA 400 KM UNLESS NOVEL MISSION MODES ARE ADOPTED
- OPERATIONAL STATION NEEDS MANY BERTHING PORTS AND MOBILE CRANE OR RMS

SPACE BASED OTV ACCOMMODATIONS





EMERGING NEEDS FOR ATTRIBUTES AND ARCHITECTURAL CHARACTERISTICS

The mission analyses we have carried out indicate a number of general needs for attributes and architectural characteristics as summarized on the facing page.

Space Station

Emerging Needs for Attributes and Architectural Characteristics

NASA SS-096

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NEED	SOURCE OR RATIONALE
FLY IN LOW INCLINATION LOW EARTH ORBIT	OPERATIONS MISSIONS; SERVICING ASTROPHYSICAL OBSERVATORIES
FLY IN HIGH INCLINATION LOW EARTH ORBIT	SCIENTIFIC AND NATIONAL SECURITY MISSIONS
FLY IN HIGH INCLINATION HIGH EARTH ORBIT	NATIONAL SECURITY MISSIONS
FLY EITHER EARTH ORIENTED OR INERTIAL	SCIENCE MISSIONS
GENERAL PURPOSE LAB PLUS RETURNABLE LAB	SCIENCE MISSIONS
FORMATION FLY WITH FREE-FLYERS	SCIENCE AND COMMERCIAL MISSIONS
GENEROUS WORKSHOP AND WAREHOUSE SPACE	NEED TO MINIMIZE TRANSPORTATION CHARGES FOR DIVERSE SCIENCE MISSIONS
MOBILE CRANE OR RMS	OPERATIONS MISSIONS
HANGARS	OPERATIONS AND NATIONAL SECURITY MISSIONS
MULTIPLE BERTHING PORTS	MISSION DIVERSITY
SECURABLE CONTROL ROOM	ACCOMMODATION OF CLASSIFIED MISSIONS
AUTONOMY	NATIONAL SECURITY MISSIONS
MINIMUM RESUPPLY	NATIONAL SECURITY MISSIONS
SAFE HAVEN AND REDUNDANCY	CREW SAFETY
SEPARATE WORK AND FREE-TIME AREAS	CREW WELL-BEING

ARCHITECTURAL TRADES AND ISSUES

A number of the planned architectural trade studies are suggested on the facing page. These will be evaluated according to the top level criteria listed. We observe that there is an inherent conflict between the desire to deal with architectures at a high level, avoiding point designs, and the need to understand specific feasibility issues including weight, center of gravity, technology, risk, packaging, crew factors, cost, and operational feasibility.

To the extent practical we will use general trending data from prior studies to correlate specific weight and c.g. information as well as packagability and utilization of internal volume with module concepts at a relatively gross level. We do, however, plan to go to a substantial level of detail on certain specific module concepts in order to establish their feasibility and compatibility with the operational scenarios.

Space Station

Architectural Trades and Issues

NASA

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ARCHITECTURAL TRADE STUDIES

- ALLOCATION/EMBODIMENT OF FUNCTIONS – MANY SPECIALIZED VERSUS FEW GENERAL-PURPOSE MODULES
- NEED FOR/USE OF PRESSURIZED WORKSHOP
- STANDARDIZATION: WHAT, HOW CONSTRAINTS AND PENALTIES
- WORK SPACE NEEDS, ALLOCATION AND USE IN RESPONSE TO MISSION NEEDS
- UTILIZATION AND ALLOCATION OF INTERIOR SPACE IN RESPONSE TO OPERATIONAL, SCIENCE AND CREW NEEDS
- LAB FUNCTIONS – GENERAL PURPOSE; DEDICATED, RETURNABLE
- ARRANGEMENT FACTORS, E.G. SYMMETRY; INERTIAS
- USE AND OPERATIONAL MANAGEMENT OF FREE FLYERS
- URBAN SPRAWL VERSUS SMALL-IS-BEAUTIFUL = BIG VERSUS SEVERAL SMALL STATIONS

TOP LEVEL CRITERIA

- MISSION SUITABILITY AND USER-FRIENDLY ASPECTS
- COST AND FUNDABILITY
- CREW FACTORS; SAFETY
- OPERABILITY, E.G. CAN IT BE ASSEMBLED?
- PRODUCTIVITY AND EFFICIENT CREW USE
- ADAPTABILITY TO THE UNKNOWN REAL FUTURE
- INSTITUTIONAL SUITABILITY
- COLLATERAL BENEFITS, E.G. USEFULNESS OF TECHNOLOGY

DESIRE TO STAY GENERAL AND AT HIGH LEVEL; AVOID POINT DESIGNS

ARCHITECTURAL OPTIONS DEFINITION

NEED TO UNDERSTAND

- WEIGHT
- CG
- TECHNOLOGY AND RISK
- COST
- CREW FACTORS
- PACKAGING
- OPERATIONAL FEASIBILITY

THERE ARE MANY CONCEPTS FOR SPACE STATIONS

The number of space station architectures that might be proposed is essentially infinite. It can range from small space stations in the salyut class to large space stations housing dozens of people and employing novel features such as reused external tanks. We are applying a systematic approach to architecture analysis selection evaluation and definition in order to provide understandable rationale and logic for the architectures we will present at the conclusion of the study.

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Space Station

There are Many Concepts for Space Stations

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OF POOR QUALITY

APPROACH TO ARCHITECTURAL OPTIONS

We have defined two general classes of architectures. The limited class presumes the use of shuttle for delivery and assembly of the space stations and that the space stations will fly in low Earth orbits. The open class admits the use of high Earth orbits, modified external tanks, heavy lift vehicles, and any other system within the state-of-the-art that might provide a beneficial attribute to the space station. Although we plan to invest relatively little effort in open class architectures, we want to understand the nature of benefits that might be derived therefrom and to describe the lessons learned. We will probably recommend one open class architecture in our final architectural options.

We are presently developing initial architectural concepts that characterize an exemplify each trade and issue. These concepts will be evaluated using selection criteria as well as other design considerations. We are finding compatibilities as well as conflicts. We will determine conflict resolution options, make a final evaluation, and select the most promising architectural options.

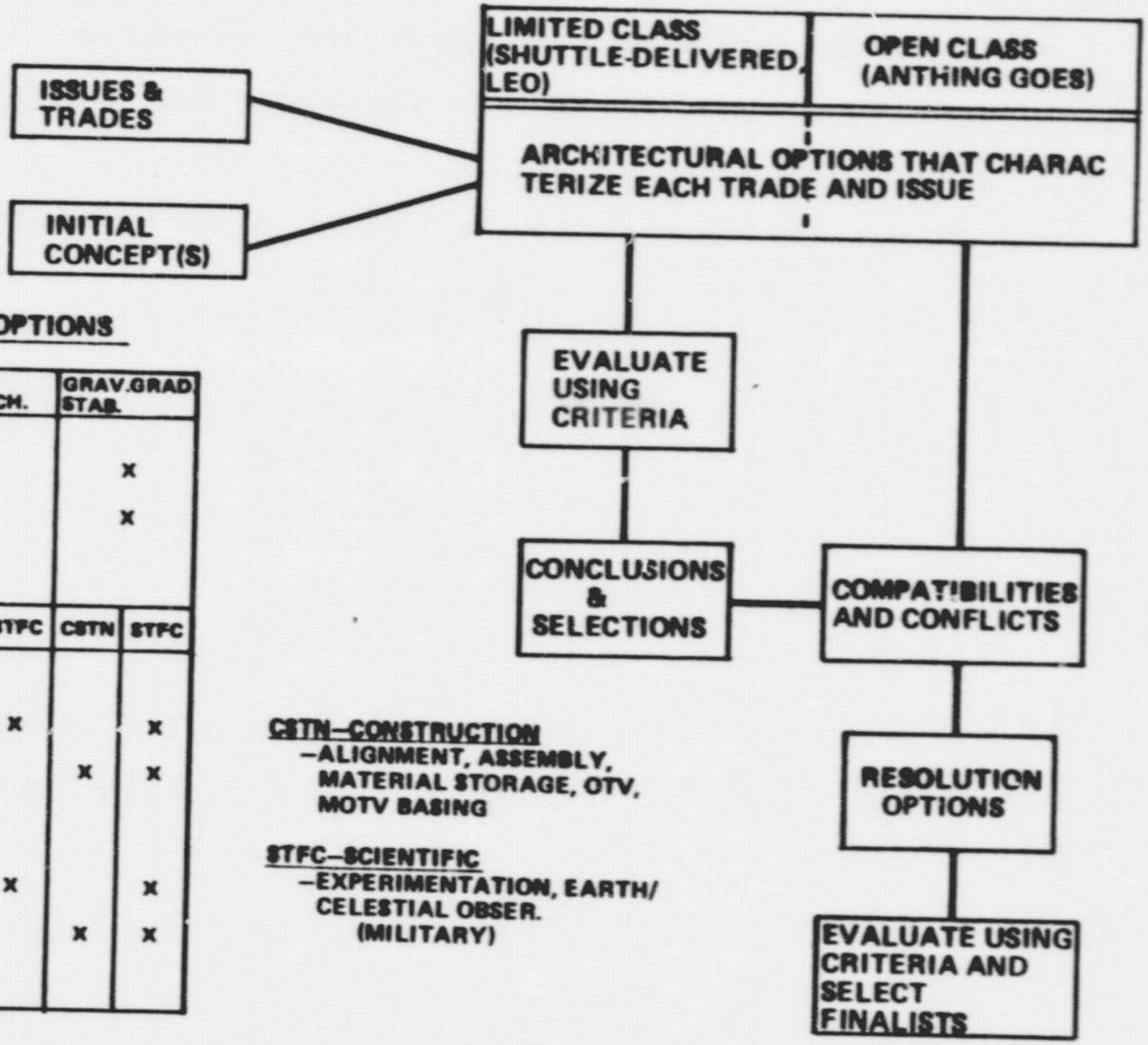
To the lower left of the chart we have shown an example range of architectural option considerations. These include three levels of space station: an initial option, an operational station, and an evolved station. For each there is a range of orientations and a range of missions. Each X on this chart is the basis for an architectural option. All of these are in the process of definition at the present time.

Space Station

NASA

Approach to Architectural Options

BOEING



FLIGHT MODES & ORIENTATION OPTIONS

	INERTIAL		EARTH ORIENT.		SUN SYNCH.		GRAV.GRAD STAB.	
ARCHITECTURE BASELINE								
90° INC WTR	X		X		X		X	
28.5 INC ETR	X		X				X	
	CSTN	STFC	CSTN	STFC	CSTN	STFC	CSTN	STFC
OPERATIONAL								
90° INC WTR		X		X		X		X
28.5 INC ETR	X	X	X	X			X	X
FUTURE								
90° INC WTR	X	X		X		X		X
28.5 INC ETR	X	X	X	X			X	X

CSTN—CONSTRUCTION
—ALIGNMENT, ASSEMBLY, MATERIAL STORAGE, OTV, MOTV BASING

STFC—SCIENTIFIC
—EXPERIMENTATION, EARTH/ CELESTIAL OBSER. (MILITARY)

TECHNOLOGY AND COST DRIVERS

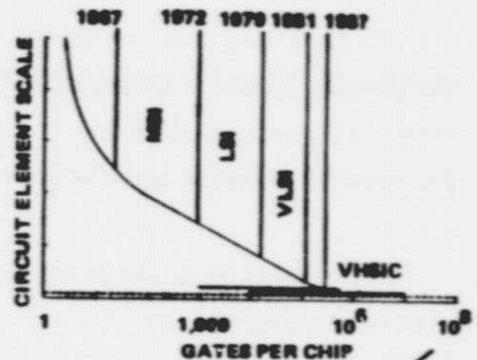
We have identified five technology opportunities that represent significant leverages for improving system capability, useful lifetime, growth potential and mission utility. These include data management and network architecture expert systems, controll dynamics, long life thermal control and the use of integrated hydrogen oxygen systems. We will consider the important cost drivers in defining the recommended program and architectural options.

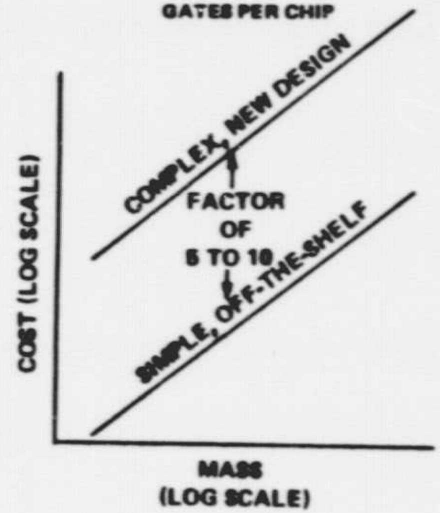
Space Station

Technology & Cost Drivers

NASA SS-040 BOEING

	WHAT	WHY
TECHNOLOGY	DATA MANAGEMENT ARCHITECTURE, HARDWARE AND SOFTWARE	CAPABILITY, COST, GROWTH PATHS, USER CONVENIENCE, AUTONOMY
	ARTIFICIAL INTELLIGENCE, EXPERT SYSTEMS	AUTONOMY, WORKLOAD RELIEF, SURVIVABILITY
	CONTROL DYNAMICS	VARIABLE CONFIGURATION; PRECISION POINTING
	LONG-LIFE THERMAL CONTROL AND THERMAL BUSSING	MITIGATE/ELIMINATE THERMAL CONTROL SURFACE DEGRADATION. HANDLE MIGRATING LOADS
	INTEGRATED HYDROGEN-OXYGEN SYSTEMS	POWER SUPPLY FLEXIBILITY; REDUCED RESUPPLY; REDUCED MASS & COST
COST	SYSTEM AND INTEGRATION COMPLEXITY	COMPLEXITY BREEDS MISUNDERSTANDING AND TAKES A LOT OF WORK TO DEVELOP/MANAGE
	UNDERSTANDING THE JOB	FALSE STARTS CAUSE SCHEDULE SLIDES AND CHANGES; HIGH COST TO SET RIGHT
	EXCESSIVE REQUIREMENTS	COMPLEXITY; DIFFICULT PERFORMANCE GOALS





STUDY EXTENSION RECOMMENDATIONS

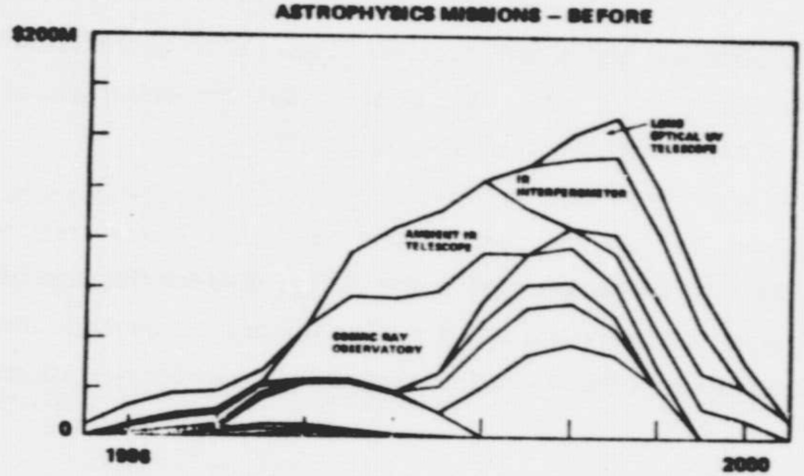
We see two primary objectives for a study extension. We expect the aggregated mission requirements collected during the present phase to substantially exceed the program's capability to afford accommodations. Consequently, a considerable effort will be needed in defining mission equipment and mission accommodations to the degree necessary to estimate costs, followed by analyses and discussions to prioritize missions according to costs, benefits, and scientific importance.

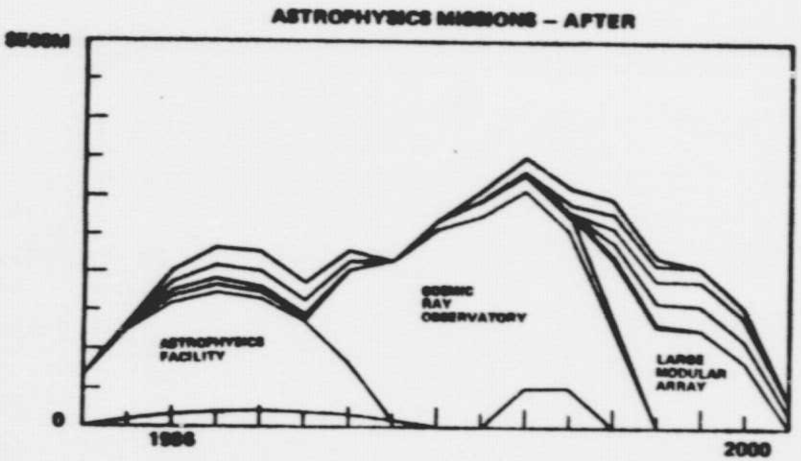
Once this is accomplished, it should be a relatively straightforward task to review the recommended architectural options and select from among them the one that is preferred for the initial space station program. A part of this task will be to include consideration of recommended foreign involvements from the ESA, Canadian, and Japanese studies.

Space Station

Study Extension Recommendations

SS-187





- DETAILED ACCOMMODATIONS AND OPERATIONS ANALYSES
  - USER INPUT MISSIONS WILL EXCEED PROBABLE PROGRAM CAPABILITIES
- RATIONALIZE AND PRIORITIZE MISSION NEEDS AND MODELS
- INCORPORATE FOREIGN INPUTS
- DEVELOP PROGRAM SCENARIOS COVERING A RANGE OF FUNDING LEVELS/SCENARIOS
- NATIONAL SECURITY MISSIONS: ANALYZE/TRADE HIGH ORBIT OPERATIONS; EVALUATE SURVIVABILITY AND SELECT STRATEGIES
- SELECT ARCHITECTURE AND TECHNOLOGIES
- CONFIRM ARCHITECTURE FEASIBILITY AND PRACTICALITY THROUGH CONCEPTUAL DESIGN AND ANALYSIS

Midterm Impressions and Future Plans

We believe that the user-contact orientation of the present studies was highly constructive. It gave us an appreciation for user attitudes and needs that would not have been acquired in any other way. We believe that the definition of architectural options and the later preliminary design definitions will benefit greatly from this initial effort.

Our plans include much effort on an accommodations analysis, to translate user mission needs into space station requirements. We are investing IR&D funds into upgrading software that we used earlier in the SOC studies for this kind of analysis. The software system was extremely beneficial in helping us to understand space station mission accommodation needs in detail; the upgrades in work will make the software as penetrating in the scientific missions as it was for operations missions.

Space Station

Midterm Impressions and Future Plans

NASA BOEING

SS 177

- User contacts have provided depth and breadth of understanding
- Not a shortage of missions. Issues are priorities; cost versus benefits
- Emerging benefits are real and substantial
- Architectural questions can be surrounded and answered; options supported with rationale
- National security aspects are intriguing – on the trail of some high payoffs
- Missions and systems requirements definition
- Accommodations analysis
  - Transportation operations, facilities use; services use; crew use
- Architectural options synethsis synthesis
- Programmatics and cost

SCIENCE AND APPLICATIONS MISSIONS

Science and application experiments are anticipated to be a major part of the Space Station instrumentation, particularly during the early part of the program. NASA has acquired a vast amount of experience with satellite-borne research equipment. A vast amount of literature has also accumulated about past missions and future planned research activities with large spacecraft. We are accumulating information about future space and application missions for the space station through our subcontracts with Science Applications Incorporated and the Environmental Research Institute of Michigan, through direct inquiries to the user community, and through review of the published literature available to us.

Science and Applications Missions

GENERIC FIELDS OF STUDY

Research is anticipated in a wide range of science and application fields. Major fields of study are listed in the accompanying chart. Solar-terrestial research has been conducted for many years, primarily on unmanned spacecraft, and much of the research community is unaccustomed to working with a manned platform. Much of the early space-based astronomy was performed with optical telescopes, and local contamination around manned spacecraft has been a real problem; however, much larger and heavier instrumentation in future missions will require manned participation to assemble and maintain. Successful applications of remote sensing missions have demonstrated the need to fly much larger and more sophisticated sensing instrumentation. The large payload weight and power capabilities of a Space Station provide the first opportunity for serious manufacturing of new materials in microgravity environments. Of course, life sciences research has been ongoing since man first entered the weightless environment of space, and more experiments with humans, animals, and plants are needed to overcome present limitations in our ability to withstand a weightless environment for long periods.

Generic Fields of Study

- Solar-terrestrial
  - Space plasma physics
  - Aeronomy/ionosphere
  - Solar physics
- Astronomy
  - High-energy astrophysics
  - UV-VIS-IR
  - Radio astronomy
  - Planetary observations
- Relativity experiments
- Remote sensing
  - Meteorology/climatology
  - Agriculture/forestry
  - Ocean dynamics
  - Mineral exploration
- Microgravity
  - Materials
  - Pharmaceuticals
- Life sciences
  - Human
  - Animal
  - Plant

STUDY OBJECTIVES

Our ultimate study objective is to identify a set of requirements for the Space Station that will accommodate the widest possible collection of science and application experiments. To this end, we have been contacting the user community in person and through the published literature. Each major research facility has certain physical characteristics, environmental interfaces, platform requirements, and crew interfaces that must be met if the instrumentation is to work properly at the Space Station, or nearby on a remotely controlled subsatellite or tethered platform. A number of major issues need to be addressed such as data management, contamination, orientation requirements, power consumption, and thermal energy dissipation and, of course, the timeline desired by the experimenter in performing his operations.

Space Station

Study Objectives

NASA 85 078 BOEING

- Obtain descriptions of user experiments
  - Physical characteristics
  - Environmental interfaces
  - Platform requirements
  - Crew interfaces
- Summarize constraints on space station
  - Operational timelines
  - Data management
  - Contamination
  - Orientation
  - Consumption
  - Dissipation
  - Location

KEY PHYSICAL CHARACTERISTICS

There are several physical characteristics of the experiments that need to be considered in defining constraints for the Space Station. Obviously there is finite limit to the ability of the Space Station to accommodate the wide variety of possibilities. It will be important to achieve a balance among these characteristics that maximizes the scientific return on our investment in space research. This implies careful consideration of the availability of Space Station resources and the proper organization of payload experiment groups.

Space Station

Key Physical Characteristics

NASA 86-077 BOEING

- Weight
- Power
- Volume
- Telemetry
- Heat dissipation
- Operating time
- Data storage
- Data processing
- Consumables

KEY ENVIRONMENTAL INTERFACES

Many science and application experiments are sensitive to environmental complications that deteriorate or destroy their performance. Consequently, it's vital to determine the susceptibilities of each experimental mission. Many optical systems, particularly those operating cryogenically, are disturbed by gas condensation, light reflection of nearby surfaces and particulates, and vibration or perturbation of their platform. Other experiments are frequently bothered by electrical noise due to electromagnetic interference and high-voltage current discharges. Some of these complications may be avoided by arranging for separate mounts on subsatellites or tethered platforms. The natural radiation environment may be a problem at higher altitudes, particularly in the South Atlantic anomaly and at high latitudes that pass through the auroral zone. Micrometeorite bombardment does not appear to pose a serious problem, but it cannot be ignored as the size of the sensor heads, and the complexity of the instrumentation continues to grow. Past experience has led the principal investigators to be especially wary of the local environment around manned spacecraft and special attention should be given to these issues.

Space Station

Key Environmental Interfaces

NASA 86-078 BOEING

- Gas contamination
- Light contamination
- Electrical charging
- Mounting location
- Platform vibration
- Radiation sensitivity
- Electromagnetic noise
- Micrometeoroids

KEY PLATFORM REQUIREMENTS

The majority of science and application experiments make observations and measurements of remote environments (except for materials manufacturing and life science experiments). Consequently, mounting platform conditions are critical to the performance of most of these experiments. Responses from users and the literature indicate many experiments require high latitude or polar orbiting platforms to carry out the necessary observations. Optical experiments particularly those in astronomy require continuous pointing at a target for an extended period; such operations require a separate gimballed platform or dedicated free flier. Some experiments will require boom extensions or tethered subsatellites to remove them from the local contamination environment of a manned spacecraft. However, such extensions create considerable difficulty for the flight controllers due to the more complicated dynamics of the coupled system. For those experiments that can function easily on the space platform itself, there remain serious pointing constraints and venting considerations that have to be taken into account. The architectural design of the science experiment accommodations on the Space Station will be driven by many requirements: look angles, contamination, stability, and compatibility with other experiments. As the collection of experiments grows we must assure compatibility among the existing experiments that are mounted together on a particular platform. Timely accessibility and convenient storage arrangements for the conglomeration of experimental instrumentation will become a major architectural concern.

Space Station

NASA 86-079

Key Platform Requirements

BOEING

- Orbit altitude
- Orbit inclination
- Orientation
- Integration time
- Free flyer (throw away)
- Extended boom
- Tether
- Controlled flyer (recoverable)
- Main frame (external)
- Main frame (internal)

KEY CREW INTERFACES

In the past most science and applications missions have operated without man in the loop as a real time analyst and decision maker. The complexity and versatility of the new generation of experiments that will be flown on space station missions is expected to require much more crew involvement. The operation of many experiments will be automated to a major extent; however, a number of activities will require crew involvement such as system checkout, calibration of sources and sensors, assembly of modules, repair and refurbishment of equipment, etc. Much of the flight crew interface time will involve maneuvering the large space station and maintaining a stable platform for the outward looking experiments. Mission specialists will perform extensive data analysis and interrogation of results to determine appropriate changes and modifications to software. Many targets of opportunity are anticipated that can only be identified by having man in the loop; we cannot predict when or how these opportunities will arise, but past experience in scientific research suggests that the serendipity of man will play a major role.

Space Station

Key Crew Interfaces

NASA 88-080 BOEING

- Operational timeline
- Automated versus manual
- Checkout/calibration
- Assembly/reconfiguration
- Spacecraft maneuvers
- Data analysis/decisions
- Data processing
- Image interrogation

USER INFORMATION BANK

Information for the science and applications area of this Space Station study is being acquired from three primary sources. First, Boeing has hired Science Applications, Incorporated and the Environmental Research Institute of Michigan as subcontractors to provide assistance in monitoring the user community and assembling detailed, quantitative information. SAI is primarily responsible for establishing contact with the physical sciences user community through letters of inquiry, phone calls, and personal contacts. ERIM has many years of experience in remote sensing applications for military and civilian programs, and they are providing a prognosis of what that community of users will require in the space station era. Letters of inquiry have been sent to more than 200 potential space scientists in the physical, life, and remote sensing fields. These inquiries have included sample copies of the NASA User Form so that the experimentalists can address those issues of particular concern to NASA; some forms have been returned already and we plan to follow up with telephone inquiries to get the information for several more proposed activities. Since responses to these inquiries are not expected to be thorough or comprehensive, we are perusing available literature about future space science research in order to fill in the gaps.

User Information Bank

Subcontractors:	Science Applications, Incorporated
	Environmental Research Institute of Michigan
User contacts :	Physical Scientist List
	Life Scientist List
	Remote Sensing Scientist List
Bibliographies :	Earth Resources Systems Bibliography
	Space Station/Space Platform Science and Applications Payload Requirements and Accommodations Document Library
	NASA Space Systems Technology Model (5 Volumes)

USER CONTACT SUMMARY

Our responses from the scientific community to our inquiries have been mixed. Past experience has taught many physical science researchers to avoid manned spacecraft if possible, and they have not displayed much interest. Others have come forward with detailed entries in the questionnaire form provided by NASA. There is some concern that a major new manned space program will take resources from the scientific research programs, and some assurance to the contrary from NASA would be most welcome. The life sciences research community has dealt directly with NASA for the most part in the past and has not shown much inclination to respond to our questionnaire in writing or by telephone. So far, the remote sensing community has responded very favorably to this opportunity because they view it as a chance to fly much larger sensor instrumentation, provided contamination can be avoided (particularly on cryogenic systems). Overall, we anticipate these letters of inquiry will reveal some significant new concepts and potential new drivers in the NASA plans for the space station.

Space Station

Space Station User Contact Summary

NASA SS-186 BOEING

SUBJECT	NUMBER OF INQUIRIES	NUMBER OF RESPONSES *	POSITIVE	NEGATIVE
PHYSICAL SCIENCES	137	25	16	9
LIFE SCIENCES	54	1	1	
REMOTE SENSING	51	4	4	
TOTALS	242			

* AS OF NOVEMBER 10, 1982

DESIGN REFERENCE MISSIONS
SCIENCE INSTRUMENTS/FACILITIES

In cooperation with the scientific community, NASA has prepared a number of studies of proposed science payloads and missions that might be flown on the Space Shuttle and its platform derivatives. The Design Reference Missions for the Science and Applications Space Platform (SASP) provide a useful starting point for us to assess the future missions that are appropriate for a space station. These instruments and facilities, in general, are very large and bulky units that require major amounts of consumables, substantial heat dissipation capability, generate huge quantities of data, and appreciable maintenance during their long lifetime in space. The physical requirements for these experiments have been well documented in earlier studies. The information has been used here to illustrate our approach in assessing the scientific and application user requirements that are anticipated for a Space Station. The results of this initial study will be supplemented with information from the user community as returns arrive from our inquiries.

Space Station

Design Reference Missions
Science Instruments/Facilities

NASA SS 181 BOEING

RESEARCH AREA	INSTRUMENTS/FACILITIES
ASTRONOMY	SHUTTLE INFRARED TELESCOPE FACILITY (SIRTF)
	VERY LONG BASELINE LINE INTERFEROMETRY (VLBI)
HIGH ENERGY ASTROPHYSICS	ELEMENTAL COMPOSITION AND ENERGY SPECTRA OF COSMIC RAY NUCLEI (SCRN)
SOLAR PHYSICS	SOLAR OPTICAL TELESCOPE (SOT)
SPACE PLASMA PHYSICS	SPACE EXPERIMENTS WITH PARTIAL ACCELERATORS (SEPAC)
	WAVE INJECTION IN SPACE (WISP)
MATERIALS SCIENCE	ELECTROPHORESIS OPERATIONS IN SPACE (EOS)
	ADVANCED MATERIALS EXPERIMENT ASSEMBLY (MEA)
EARTH OBSERVATION	OCEAN WAVE DIRECTIONAL SPECTROMETER (OWDS)
	ADVANCED LIMB SOUNDER (ALS)
	LAND OBSERVING RADAR (SYNTHETIC APERTURE RADAR)

DESIGN REFERENCE MISSIONS
SCIENCE INSTRUMENTS/FACILITIES

Continuation of preceding chart.

Space Station

Design Reference Missions
Science Instruments/Facilities

NASA BOEING

SS 183

RESEARCH	INSTRUMENTS/FACILITIES
ASTRONOMY	STARLAB
HIGH ENERGY ASTROPHYSICS	TRANSITION RADIATION AND IONIZATION CALORIMETRY (TRIC) SUPERCONDUCTING MAGNETIC SPECTROMETER (SUPERMAG) HEAVY NUCLEI EXPLORER (HNE) LARGE AREA COSMIC RAY DETECTOR (LACRD) HIGH RESOLUTION X-RAY SPECTROMETER (HRXS) LARGE AREA MODULAR ARRAY OF REFLECTORS (LAMAR)
MATERIALS SCIENCE	SOLIDIFICATION EXPERIMENT SYSTEM (SES)
ENVIRONMENTAL OBSERVATION	ACTIVE CAVITY RADIOMETER (ACR) SOLAR ULTRAVIOLET IRRADIANCE MONITOR (SUSIM) ADVANCED MICROWAVE SOUNDING UNIT (AMSU)

PHYSICAL SCIENCE MISSIONS—MAJOR INSTRUMENTS

The design reference missions for SASP have been tabulated by instrument according to their specific generic scientific missions. Some of these instruments have already been built and flown on early Space Shuttle missions; others are in various stages of development; still others remain in the planning stages, usually under the direction of a committee of users. Overall pointing requirements are virtually omnidirectional in view of the wide diversity of targets of interest. Most of these experiments prefer a high latitude inclination in the Station orbit since it provides better coverage of targets of interest. In view of the energy requirements to establish polar orbits for large spacecraft, this experimental constraint will become an important driver in design deliberations.

Space Station

Science Missions-Major Instruments

NASA 86-036 BOEING

INSTRUMENT / MISSION	ASTRONOMY	HIGH ENERGY ASTROPHYSICS	SOLAR PHYSICS	SPACE PLASMAS	MATERIALS	EARTH OBSERV	PICTURE	STATUS	POINTING	ORBIT
SIRTF SHUTTLE IR TELESCOPE FACILITY	X							IN DEVEL	SPACE	MD LEO
VLBI VERY LONG BASELINE INTERFEROM	X							PLANNED	SPACE	MD LEO
SCRN SPECTRAL COMPOS. OF COSMIC RAYS		X						PLANNED	SPACE	MD LEO
SOT SOLAR OPTICAL TELESCOPE			X					PLANNED	SUN	HI LEO
SEPAC PARTICLE ACCELERATORS				X				AVAIL	EITHER	HI LEO
WISP WAVE INJECTION IN SPACE				X				AVAIL	EITHER	HI LEO
EOS ELECTROPHORESIS OPERATIONS IN SPACE					X			IN DEVEL	ANY	ANY
MEA MATERIALS EXPT ASSEMBLY					X			PLANNED	ANY	ANY
OWDS OCEAN WAVE DIRECT SOUND						X		PLANNED	EARTH	HILEO
ALS ADVANCED LIMB SOUNDER						X		IN DEVEL	LIMB	HILEO
SAR SYNTHETIC APERTURE RADAR						X		IN DEVEL	EARTH	HILEO

Space Station

Science Missions-Major Instruments (Cont'd)

NASA 85-034 BOEING

INSTRUMENT \ MISSION	ASTRONOMY	HE ASTROPHYSICS	SOLAR PHYSICS	SPACE PLASMAS	MATERIALS	EARTH OBSERV.	PICTURE	STATUS	POINTING	ORBIT
TRIC TRANSITION RADIATION & IONIZATION CALORIMETER		X						OPPORTUNITY	SPACE	MDLEO
SUPERMAG SPECTROMETER		X						OPPORTUNITY	SPACE	
HNE HEAVY NUCLEI EXPLORER		X						OPPORTUNITY	SPACE	MDLEO
LACRD LARGE AREA COSMIC RAY DETECT		X						PLANNED	SPACE	ANY
SES SOLIDIFICATION EXPT SYSTEM					X			OPPORTUNITY	ANY	ANY
AXAF ADV X-RAY ASTROPHYS FACILITY	X	X	X					PLANNED	SPACE	MDLEO
SUSIM SOLAR UV IRRADIANCE MONITOR			X					PLANNED	SUN	MDLEO

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SCIENCE PAYLOAD REQUIREMENTS

Some key operating parameters of the design reference missions are plotted to show the variety of constraints that would be imposed by these missions on a large space platform, such as the Space Station. Launch weight for several of the missions are many tons and very bulky in size. Consequently, several shuttle missions would be required to carry a complement of experiments such as this into low Earth orbit. The power consumption of these experiments is a strong cost driver in the program since large solar panels or a nuclear reactor will be required to accommodate the demand. Furthermore, the heat generated by this power requirement will need to be dissipated by appropriate thermal radiators. Every experimenter would like to operate his equipment whenever targets of opportunity are available; with the exception of earth observation experiments, this implies almost continuous operation for all experiments which is clearly impractical. Our estimates of the time available for use of the different experiments is based on crew availability, spacecraft maneuverability, data channel capability, and current mission experience with the Space Shuttle and Skylab. As more manpower and remote platforms become available on the Space Station, extended periods of time for experiment operation would probably become available.

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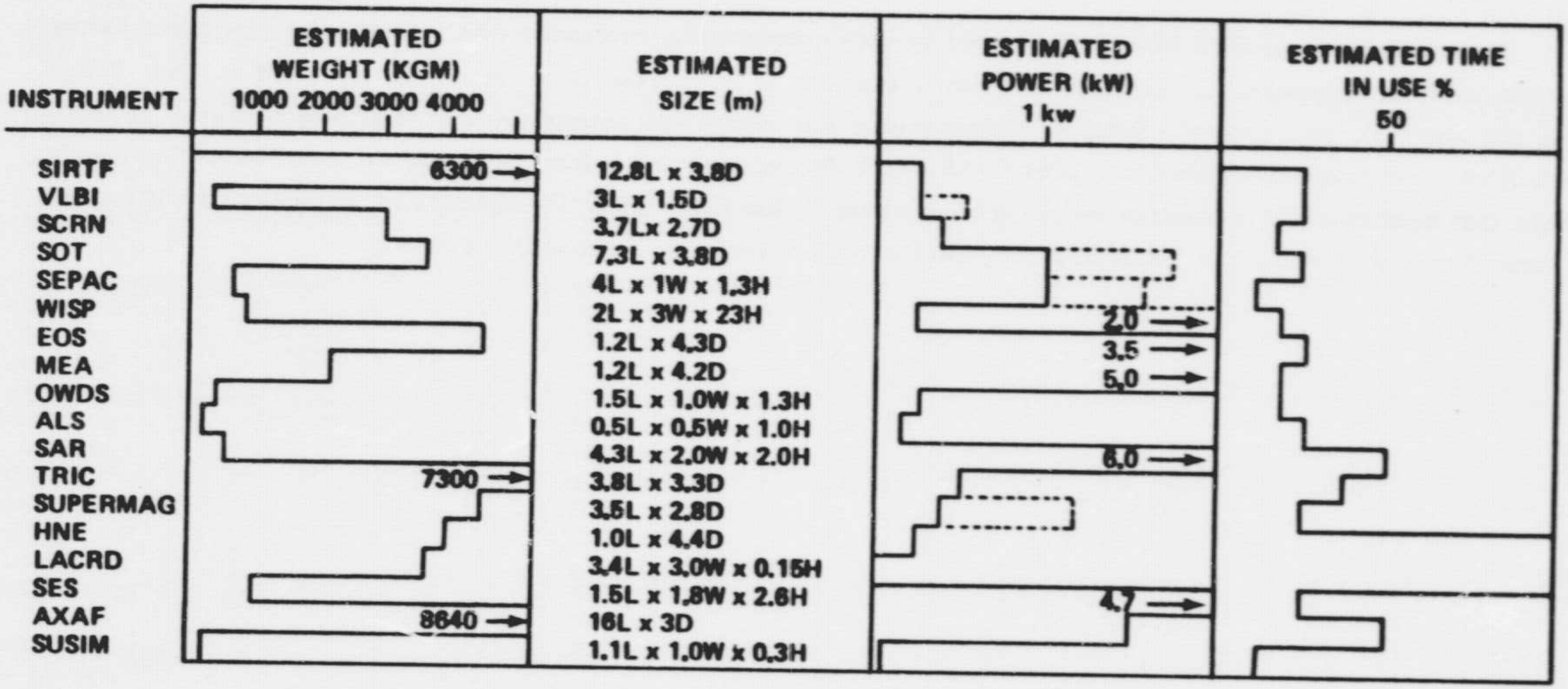
Space Station

Science Payload Requirements

NASA SS-142 BOEING



INSTRUMENT	ESTIMATED SIZE (m)
SIRTF	12.8L x 3.8D
VLBI	3L x 1.5D
SCRN	3.7Lx 2.7D
SOT	7.3L x 3.8D
SEPAC	4L x 1W x 1.3H
WISP	2L x 3W x 23H
EOS	1.2L x 4.3D
MEA	1.2L x 4.2D
OWDS	1.5L x 1.0W x 1.3H
ALS	0.5L x 0.5W x 1.0H
SAR	4.3L x 2.0W x 2.0H
TRIC	3.8L x 3.3D
SUPERMAG	3.5L x 2.8D
HNE	1.0L x 4.4D
LACRD	3.4L x 3.0W x 0.15H
SES	1.5L x 1.8W x 2.6H
AXAF	16L x 3D
SUSIM	1.1L x 1.0W x 0.3H

APPLICATIONS

The applications missions have been grouped by very encompassing categories that include many disciplines having similar platform requirements. Instruments shown are meant to be representative of a type and need so their design characteristics are quite general. Some of the instruments will require new development; some already exist in some form, still other are proposed opportunities. Codes S1-S5 denote development states from "availabe" to "new idea". The matrix shows that missions could be satisfied by one or more sensors in low Earth orbit. The constant watch missions would require a constellation of free flying satellites to accomplish their objectives in low Earth orbit, however.

Space Station

Applications

NASA SS 037 BOEING

INSTRUMENT \ MISSION	METEOROLOGY & CLIMATOLOGY	AGRICULTURE & FORESTRY	OCEAN DYNAMICS & RESOURCES	TRANSIENTS (DETECT, TRACK, IDENTIFY, C^3)	LAND-WATER USE	GEOLOGY	INSTRUMENT CHARACTERISTICS
IMAGING SPECTROMETER S4	LILEO HILEO	LILEO	HILEO	HILEO		HILEO	CAN BE RECONFIGURED TO MISSION OPTIMIZE IFOV, BAND-WIDTH, SWATH; POINTABLE
SYNTHETIC APERTURE RADAR S1-S2			HILEO	HILEO	HILEO LILEO	HILEO	200 NM SWATH, 10 FT RES, ON BOARD PROCESSING
LASER ALTIMETER S2-S3			HILEO			GEO HILEO	1 MM ACCURACY AT ANY ORBIT PICO SECOND PULSED, MODE-LOCKED LASER
HI-RESOLUTION IMAGER S4				GEO LEO	GEO LEO		3M REFLECTOR OPTICS, 24M f.l. OR CONSTELLATION OF SMALLER SENSORS IN LEO
MULTISPECTRAL SCANNER (THETIATIC MAPPER) S1-S2	HILEO	LILEO	HILFO		HILEO HILEO	HILEO	6 BAND, 185KM SWATH 10-20 M RES, ON BOARD MFG PROC.
SPECTRAL LIDAR S1-S2-S3	LILEO						PULSED LASER EXCITES H_2O & CO_2 FOR TEMPERATURE PROFILE, WINDS

S1: AVAILABLE
S2: IN DEVELOPMENT
S3: PLANNED
S4: OPPORTUNITY
S5: NEW IDEA

APPLICATIONS PAYLOAD REQUIREMENTS

As in the physical science payload requirements chart, estimates are presented of some of the key operational parameters that will influence the design of the Space Station. All of the instruments have receiving optics or antennas of appreciable size. Even more significant are the large power requirements of many of these systems. The synthetic aperture radar will itself require such a vast amount of power that a nuclear reactor can only satisfy its need. Our estimates of the use time allowable are based on limited information available, and mission experience; they are driven by the needs of the user group and the ability of the Station to accommodate the power requirements, data processing, and target acquisition and integration time.

Space Station

Applications Payload Requirements

NASA 85-036

BOEING

INSTRUMENT	ESTIMATED WEIGHT (KG) 50 100 150	ESTIMATED SIZE (M)	ESTIMATED POWER (KW) 1 2 3 4	ESTIMATED % TIME IN USE 50 100
IMAGING SPECTROMETER		1.2L x 1.2W x 1.2H		
SYNTHETIC APERTURE RADAR		20L x 5W x 5H	100'	
LASER ALTIMETER		3L x 2D		
HI-RES IMAGER		3L x 3W x 1H	2	
MULTISPECTRAL SCANNER		2L x 2D	1	
SPECTRAL LIDAR		3L x 6D	5	

LIFE SCIENCES

Some operational parameters for major generic areas of life science experimentation are presented in this chart.

Space research in the biological sciences is usually divided into human biomedical tests, small animal physiology, and botany. The biomedical investigations are motivated by spacecraft crew needs for comfort and safety. While many of these tests have been self administered in the past, the larger facilities and additional crew numbers in a Space Station permit medical personnel to participate on missions and perform more complex laboratory tests during flight. Planning for vertebrate and primate facilities are underway. They would require an extensive array of animal cages, a variety of probes, and monitoring instrumentation. Feeding and waste removal for many animals in a weightless environment imposes unique demands on the station laboratory. Although plant research is relatively passive, provisions must be made to assure proper environmental conditions and allow for adequate monitoring instrumentation.

Space Station

Life Sciences

NASA BOEING

SS-154

	CARDIOVASCULAR/ PULMONARY	MUSCULO SKELETAL	HEMATOLOGY/ IMMUNOLOGY	VESTIBULAR	NEUROSURGERY/ PHYSIOLOGY	RADIATION BIOLOGY	REPRODUCTION	FLUIDS ELECTROLYTES	PLANT DEVELOPMENT	PLANT PHYSIOLOGY
BIOMEDICAL MEASUREMENTS UNIT (HUMAN)	X	X	X	X	X	X		X		
PRIMATE HOLDING UNIT	X	X	X	X	X	X	X	X		
SMALL VERTEBRATE HOLDING UNIT	X	X	X	X	X	X	X	X		
VERTEBRATE MEASUREMENT UNIT	X	X	X	X	X	X	X	X		
PLANT HOLDING UNIT (EACH)									X	X
PLANT MEASUREMENT UNIT									X	X

Space Station

NASA SS-155

Life Sciences

BOEING

	WEIGHT	SIZE M^3	POWER	TIME
BIOMEDICAL MEASUREMENTS UNIT (HUMAN)	300 KG	2	450 WATTS	2 HOURS/DAY
PRIMATE HOLDING UNIT	150 KG	?	25 WATTS	24 HOURS/DAY
SMALL MAMMAL HOLDING UNIT	136 KG	.2	130 WATTS	24 HOURS/DAY
VERTEBRATE MEASUREMENT UNIT	140 KG	10	70 WATTS	?
PLANT HOLDING UNIT (PER UNIT)	130 KG	.2	10 WATTS	24 HOURS/DAY
PLANT MEASUREMENT UNIT	160 KG	1.5	28 WATTS	?

USE OF MAN

The availability of astronaut crew members to service the science and applications missions offers many performance options. As indicated in the accompanying chart, direct involvement with the hardware permits much more flexible utilization of the systems because changes are possible: easier pointing at targets, rapid assessment of performance, modifications of hardware and software, repair and calibration of sensors and instrumentation, etc. This versatility can only be achieved, however, if the hardware is designed to accommodate it. Most space science researchers have not built equipment to be serviced by astronauts during space operations. Consequently, their designs have been fully integrated rather than modular. New approaches to hardware design that allows easy access should be encouraged in the scientific community. More reliance on software to control operational modes should be encouraged.

Crew involvement is even more apparent in applications-oriented Earth observations. His adaptability allows him to respond to a wide variety of needs, especially to images which were not predicted when instruments were designed. Man's capabilities for pattern recognition allow him to distinguish subtle changes from surrounding areas. The ability to distinguish thousands of hues obviates the need for instruments with many, many spectral channels. Together, these abilities for pattern recognition and spectral resolution assist man to do what he probably does best—to interpret information and draw conclusions in real time. This enables him to decide where to look and what instruments to use for the best result. Finally, his memory of previous patterns and changes over time allow him to make predictions and respond to cognitive features without losing information due to a data glut.

Space Station

NASA

SS-012

Use of Man

BOEING

- Unique Advantages
  - Assemble, deploy, operate, maintain, reconfigure
  - "Real Time" analysis and decisions
  - Continuity of operation
  - Flexibility of operational modes
- Increased Capacity to Accomplish Missions
  - Much shorter lead time
  - Lower cost for repeated activities
  - New mission possibilities

SPACE STATION SCIENCE AND APPLICATIONS

EXPERIMENT CLASSES

Minimal Interaction - Experiments such as plant, bacteria or crystal growth. The experiment makes use of the zero gravity and/or high vacuum environment. The crew need only place the experiment in the proper location and supply power. Processing primarily of a monitoring nature (bits/sec).

Moderate Interaction - Experiments such as observations of well-defined targets (observations of x-rays from a number of stars, for example). The instrument requires control to perform tracking functions and intermittent crew action to select new targets and check on accumulated data. Processing requirements mode rate (kilobits/sec).

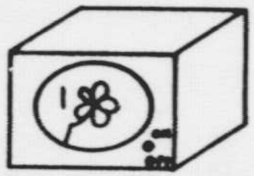
Heavy Interaction - Experiments such as real time observation and analysis of transient events. This class of experiments may require continuous crew intervention to select observation points, apply analysis algorithms and make decisions on the course of the experiment. Processing requirements could be very high (megabits/sec).

Space Station

Space Station Science and Applications Experiment Classes

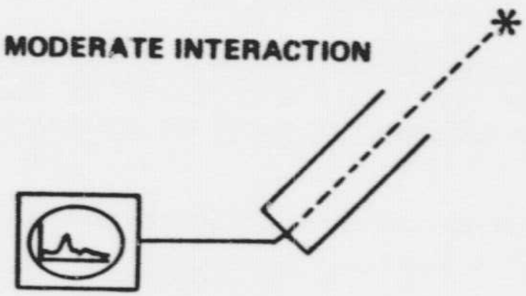
NASA — BOEING

MINIMAL INTERACTION



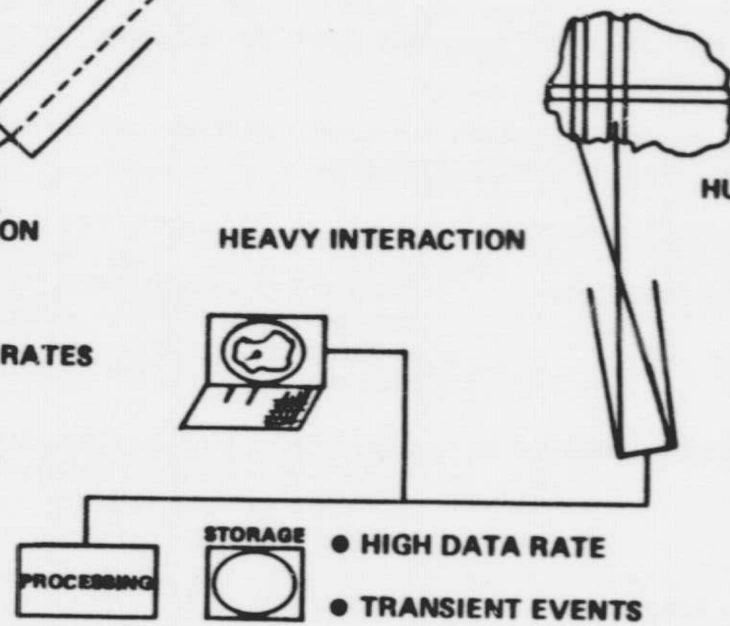
- CONSTANT ENVIRONMENT
- CONSTANT POWER
- PREDEFINED DURATION
- DIRECT RETURN TO GROUND

MODERATE INTERACTION



- TARGET SELECTION
- AUTO TRACK
- VARIABLE DATA RATES
- STORED DATA

HEAVY INTERACTION



- HIGH DATA RATE
- TRANSIENT EVENTS
- MANUAL TARGET IDENTIFICATION
- DATA BASED DECISIONS

SPACE STATION MODULE DATA PROCESSING CONFIGURATION

The data processing configuration is interconnected by a data bus or busses capable of both video and digital data transmission. Linked to the data busses are facilities for data storage, operator control consoles, necessary processors, sensors and elements being controlled.

Data storage includes the capability to store and read out both digital and video data. Video storage offers the option of a very high storage density. Advancing technology in this area may make video disc storage and readout of analog and digital data a viable alternative for relatively near term (5 years) use.

Operator consoles will provide crew personnel access to the station core operations as well as to the experiments and applications underway. Multiple entry levels to data and operations will limit operator access to information and operations concerned with their function. Operator consoles will have a limited processing capability and will include multifunction displays and controls to minimize required hardware.

The Processing Center provides the necessary processing power to handle core Space Station functions and the application and science functions. These functions will in general be alocated throughout the station and the associated processing capability would be distributed to match the function location and provide necessary system redundancy.

Sensor inputs include both the fixed station sensors necessary for operations control and the special purpose sensors involved in applications and science.

Controlled elements are driven as a result of the sensor inputs, operator actions, and processing results.

Minimal Interaction - Experiments such as plant, bacteria or crystal growth. The experiment makes use of the zero gravity and/or high vacuum environment. The crew need only place the experiment in the proper location and supply power. Processing primarily of a monitoring nature (bits/sec).

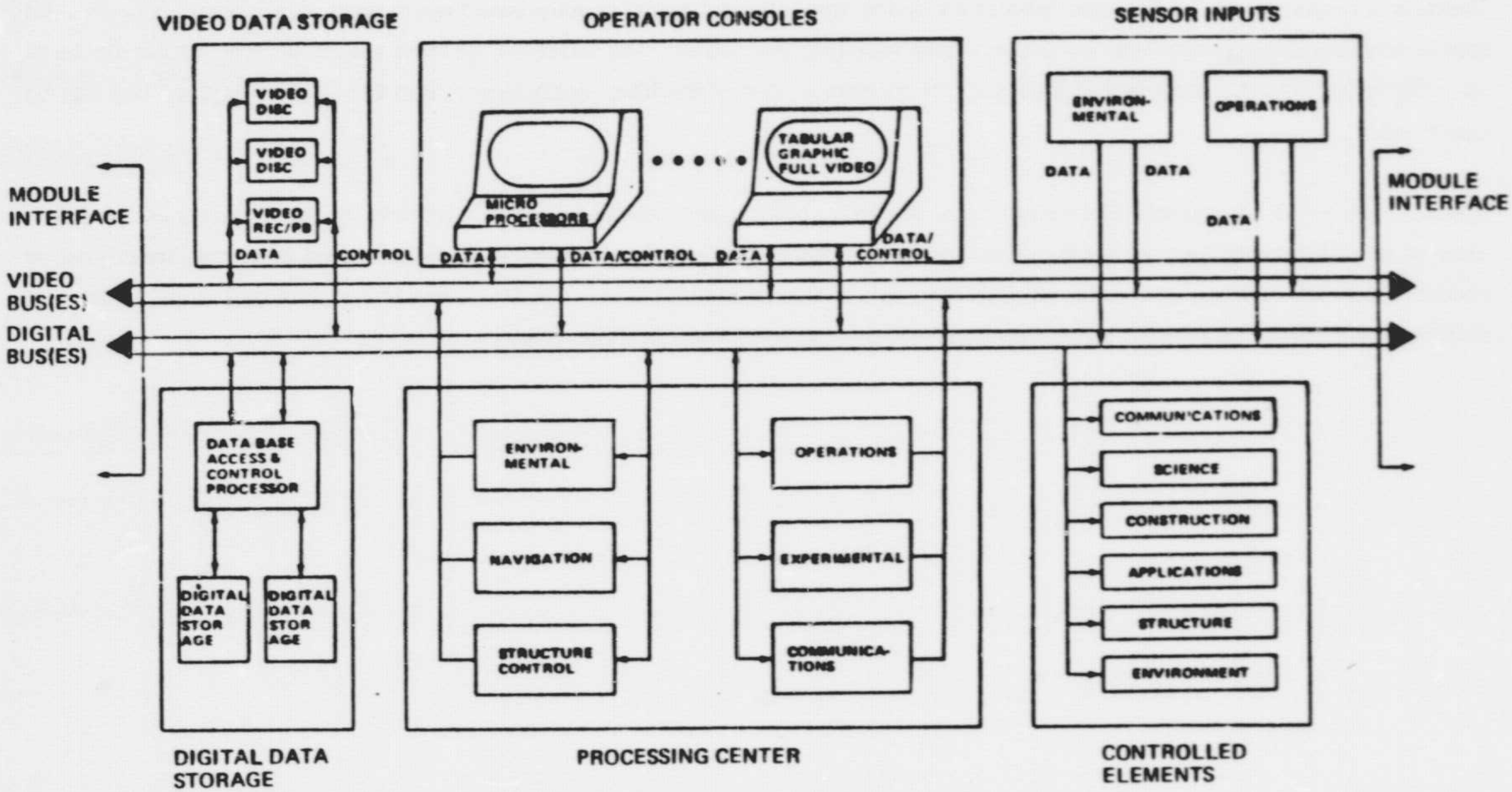
Moderate Interaction - Experiments such as observations of well-defined targets (observations of x-rays from a number of stars, for example). The instrument requires control to perform tracking functions and intermittent crew action to select new targets and check on accumulated data. Processing requirements mode rate (kilobits/sec).

Heavy Interaction - Experiments such as real time observation and analysis of transient events. This class of experiments may require continuous points, apply analysis algorithms and make decisions on the course of the experiment. Processing requirements could be very high (megabits/sec).

Space Station

Space Station Module Data Processing Configuration

NASA SS 168 BOEING



SPACE STATION ATTRIBUTES

Information gathered thus far has turned up a number of qualities that scientists would like to have on a space station. There is a requirement for internal laboratory space that allows typical ground-based operations in microgravity. A shirt sleeve environment is essential for normal data handling functions. The external systems should be able to handle large structures; particularly assembly of modular components so that assemblies much larger than the shuttle payload bay can be constructed.

Many of the usual constraints like cleanliness, stability, power, and thermal control will have to be carefully addressed in view of specific experimental needs. The mechanics and safety issues involved in deployment of boosters, freeflying or recoverable subsatellites, and tethered platforms is a major new constraint. Finally, there is a strong desire on the part of many experimenters to operate at high inclinations and polar sun-synchronous orbits.

Space Station

NASA

Space Station Attributes

BOEING

- Provide internal experiment space:
  - "Wet" laboratory – hands on experiment
  - Data handling and analysis equipment
- Have ability to assemble large external structures such as antennas, magnetic coils, etc.
- Support operation of attached remote-sensors/imagers, etc., that require moderate attitude stability and cleanliness
- Support operation of attached active experiments:
  - Transmitters, VLF to radar
  - Particle accelerators
  - Laser sounders
- Support deployment of upper stages carrying satellites to higher earth orbit or interplanetary orbit
- Release and operate interactively with separated sensor platforms of various kinds in adjacent low earth orbits:
  - Small plasma diagnostic platforms
  - Maneuverable sub-satellites
  - Highly stable, clean, and large space platforms
- Operate in both equatorial and polar orbit

Commercial Missions

COMMERCIAL MISSIONS

Three major categories of commercial missions are being addressed as user mission areas. In the Earth observation area, we are considering applications only. This includes operational systems of Earth observations with clearly identifiable benefits to commercial or government users. Materials processing missions are considered where a profitable product can be identified. In both of these areas, a distinction is made between primarily scientific missions and primarily profit-oriented missions. Communications missions considered are those which utilize a manned Space Station and which existing communications satellite companies are willing to consider.

Commercial Missions

I. Earth Observations

II. Materials Processing

III. Communications

EARTH OBSERVATION MISSIONS

A wide variety of Earth observation missions have been considered. Here is a list of missions, categorized by the object of the observation. Most of the land observation targets remain stationary, and change only seasonally, if at all. High resolution and subtle differences in patterns and hue over time and space need to be distinguished by an observer. Ocean targets change location over hours and days, in a more or less predictable pattern. Recall of locations during previous orbits assist the observer in identifying and locating given objects. Atmospheric targets change more rapidly in an Earthbound reference frame, but observation over successive orbits helps to evaluate and predict changes. Targets of opportunity are transient events which are difficult to predict and for which an adaptable observer is essential.

Space Station

Earth Observation Missions

NASA 88-041 BOEING

LAND
- AGRICULTURE
  - CROPS (UTILITY, BIOMASS, FORECASTING)
  - RANGE (OVERGRAZING, SOIL MOISTURE)
  - FORESTRY (MANAGEMENT, DISEASE)
- LAND USE
- WATER RESOURCES
  - ENVIRONMENTAL QUALITY
  - WATERSHEDS
  - FLOODS
- GEOLOGY
  - EARTHQUAKE PREDICTION
  - MINERAL LOCATION

- ATMOSPHERE
  - WEATHER FORECASTING
  - POLLUTION MONITORING

OCEAN
- MONITORING
  - SHIP LANES
  - RESOURCES
  - CURRENT CHANGES
- POLLUTION DETECTION
  - EFFLUENTS
  - SHIP AT SEA VIOLATORS

- TARGETS OF OPPORTUNITY
  - DISEASTER
    - FIRE
    - FLOOD
    - SEVERE STORM
    - SHIP RESCUE
  - OTHERS
    - VOLCANOES
    - FOREIGN MILITARY TESTS

GOVERNMENTALLY PROFITABLE

Some of the Earth observation missions are profitable to private industry from a commercial viewpoint, while others are beneficial to society but are unlikely to be funded by private enterprise. Here is a list of applications which are beneficial to society from a nonscientific, routine observation aspect. It is assumed that the user of these observations is a branch of the government.

Space Station

Governmentally Profitable

NASA 88-621 BOEING

1. Disaster Detection and Assessment
   A. Fire
   B. Flood
   C. Severe Storm
2. Search and Detection (Tracking)
   A. Ships at sea
   B. Airplane
3. Crop Production Forecasting
   A. National
   B. International
4. Pollution Monitoring
   A. Effluents
   B. Ship at Sea Violators
5. Meteorology
   A. Temperature
   B. Constituents
   C. Weather
6. Targets of Opportunity
   A. Volcanos
   B. Sudden events which impact environment
7. Habitability: Effects of man on environment

COMMERCIALLY PROFITABLE

Other Earth observation missions might be candidates for commercial applications. These tend to be missions with specific users, who would be willing to pay for information which has limited distribution.

Space Station

NASA

88 022

Commercially Profitable

BOEING

1. Forestry: Timber stand estimation
2. Agriculture: Crop monitoring
   - A. Disease
   - B. Water requirements
   - C. Nutrients
3. Ship Monitoring and Ship Lanes (air and sea)
   - A. Location
   - B. Traffic
   - C. Threats
   - D. Currents
4. Fish
   - A. Migration
   - B. "Red Tide"
   - C. Ocean temperature, streams
   - D. Nutrient streams

EARTH OBSERVATION REQUIREMENTS

The instruments which would be required for applications missions are essentially the same ones, in the same orbits, as those which are required for scientific Earth observations.

Space Station

Earth Observation Requirements

NASA 86-033 BOEING

C - COMMERCIAL VALUE
G - GOVERNMENT VALUE

	AGRICULTURE FORESTRY (C + G)	AIR/SEA MONITORS (C)	OCEAN RESOURCES (C)	TRANSIENT TARGETS (C + G)	METEOROLOGY CLIMATOLOGY (G)	ENVIRONMENTAL MONITORING (G)
IMAGING SPECTROMETER	HI-INC. LEO	HI.INC. LEO	HI.INC. LEO	HI-INC. LEO	HI.INC. LEO	
SYNTHETIC APERTURE RADAR		LEO		HI-INC. LEO		HI.INC. LEO
ALTIMETER		HI.INC. LEO		HI.INC. LEO		
MULTI-SPECTRAL SCANNER	HI.INC. LEO	HI.INC. LEO	HI.INC. LEO	HI.INC. LEO		HI.INC. LEO
HIGH RESOLUTION IMAGER		GEO	GEO	GEO	GEO	GEO
LIDAR SPECTROMETER					HI.INC. LEO	

COMMERCIAL EARTH OBSERVATION ISSUES

The key issues pertaining to applications of Earth observations generally relate to ownership and priority. Commercial enterprises achieve success by selling a product. The cost of the product, and therefore the potential for profit, depends on restricted supply. A customer will pay for a product only if he cannot get it for free (i.e., only if access to data is limited to those users willing to pay the price). This imposes a requirement for the government, who would presumably own the Space Station, to protect proprietary rights of a user. This would require the government not to publicize data gathered on its facility. If a single facility, or group of instruments is to be used by more than one commercial user, some sort of policy needs to be established regarding joint ownership of facilities, data derived therefrom, and priority of demands.

Space Station

Commercial Earth Observation Issues

NASA 85 020

BOEING

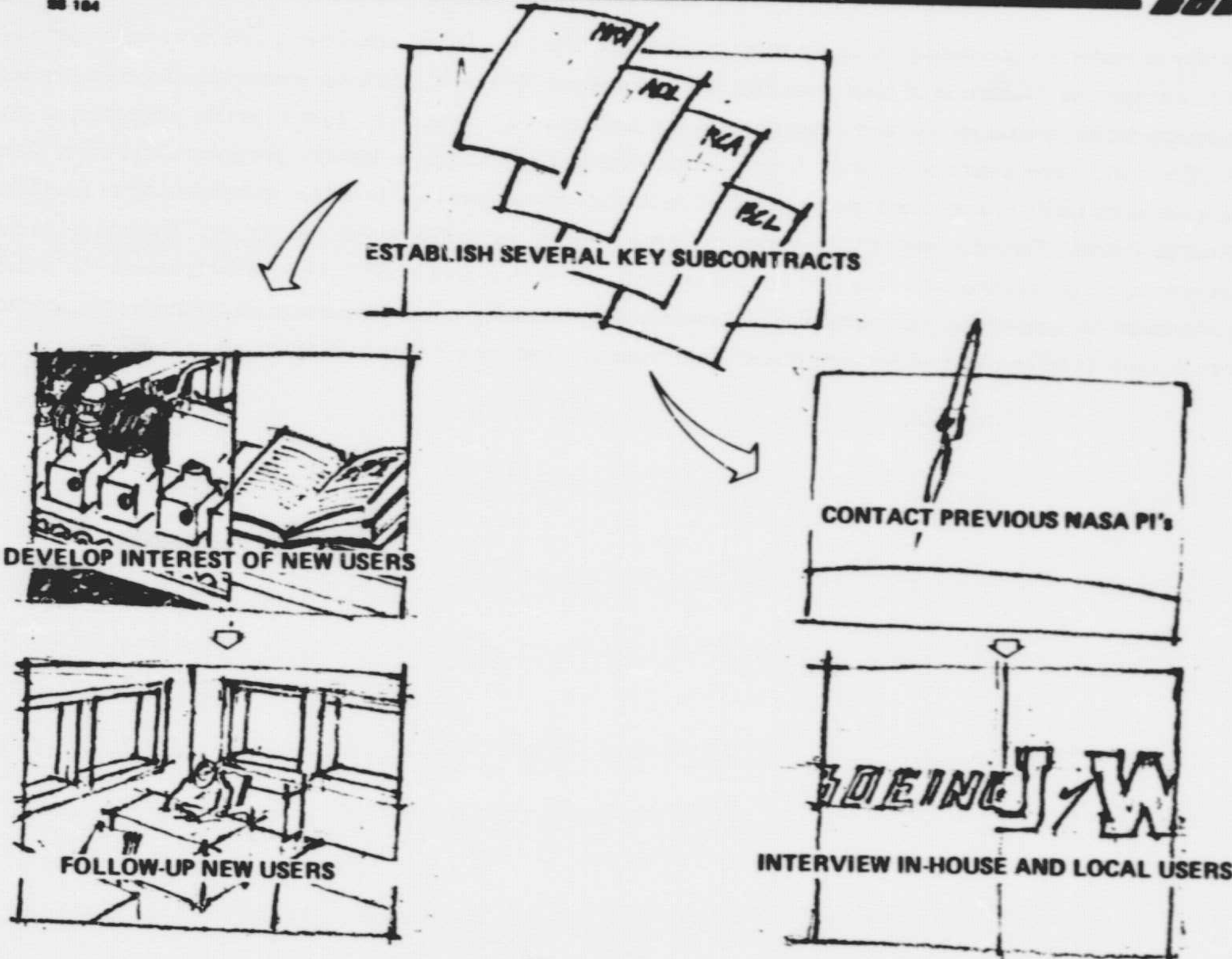
- Proprietary data
- Ownership of facilities
- Adaptability of missions
- Priority of demands for facilities

COMMERCIAL MISSIONS APPROACH

Our planning approach to the commercial mission user needs subtask has been to start earliest on the long lead-time contacts and progress to those for which a rapid response is anticipated. Following this approach, we first established several key subcontracts with companies possessing special qualifications. These were: Microgravity Research Associates, which is planning a commercial materials processing venture; RCA Stro-electronics, which may become a space station communications satellite user; Battelle Columbus Laboratories, which has planned a space-based biological materials program and has recently surveyed pharmaceutical firms for space research interest; and Arther D. Little, which has a long history of exposure to materials processing in space and has examined the institutional issues of MPS.

We then compiled a list of industries most likely to be interested in space station materials processing and predicted future trends and research areas which may be fertile for space processing. A telephone survey was conducted of senior research officers in companies which have not yet shown much interest in MPS. As these new users were evaluating their needs, we began to contact previous NASA principal investigators. These were contacted more recently with the belief that they require less time to consider their space station accommodation needs. All of these contracts will continue to be developed throughout this study and additional interviews will be held within the Boeing Company, with interested high technology companies in the greater Seattle area, and with local university researchers.

Commercial Missions Approach



MPS SCOPE

A wide variety of materials processing areas are being considered. Here is a list of areas being addressed, arranged roughly according to a subjective evaluation of their potential as a commercial MPS area. Definite commercial interest has been shown in semiconductor crystal growth and in electrophoretic separation of living cells. Containerless processing of glasses for optical filters and fibers seems promising. A metallurgical laboratory on a space station appears to offer some promise at least as a research facility, where new alloys or solidification processes may lead to better understanding of Earth-based metallurgical processes. This area seems to be currently constrained by general economic conditions. The ability to make uniform spheres is being examined and may find limited applications, probably as monodisperse latex spheres. Ceramics are being addressed because of the possibility of high temperature processing of reactive materials. Finally, the production of catalysts in space is being explored because this class of materials can have a very high value per unit mass.

MPS Scope

- Semiconductor crystal growth
- Biological materials processing
- Glass production
- Metals technology
- Uniform spheres
- Ceramics
- Catalyst production

SEMICONDUCTOR MISSION PHASES

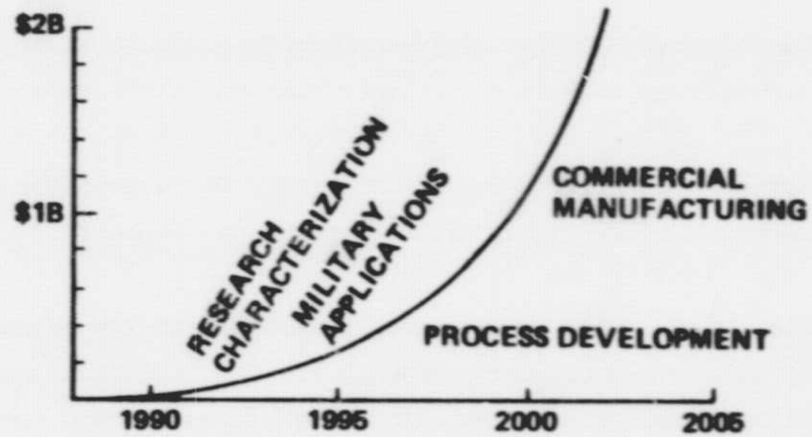
Taking gallium arsenide as an example, five phases of commercial development can be distinguished. Shuttle-based research is expected to begin in the latter half of this decade. Once production has been demonstrated on the Orbiter, a pre-commercial production phase will begin where limited quantities of high quality gallium arsenide crystals are produced on one or two Orbiter flights per year and sold to industrial semiconductor users for electronic characterization. The next two phases would be somewhat in parallel. Gallium arsenide production for military application as infrared detectors could provide a firm commercial applications objective for continued market development. Without a space station, the market will always remain quite small. With a space station, manufacturing would shift to the station as demand grew and higher availability were needed. Once crystal growth is established on board the space station and intensive process development begins, a materials characterization laboratory might then be furnished on the space station to take advantage of the resulting ability to perform many variations on the basic process, analyze the results, and interactively develop the process. This would require a skilled crew with onboard characterization facilities. This process development phase would then lead to a mature commercial manufacturing phase, with automated manufacturing facilities that are serviced from the space station.

Space Station

Semiconductor Mission Phases

NASA 86-030 BOEING

GALLIUM ARSENIDE
MARKET PROJECTIONS



1.	RESEARCH	SHUTTLE-BASED RETURN SAMPLES TO GROUND FOR ANALYSIS
2.	CHARACTERIZATION	MORE FREQUENT SHUTTLE FLIGHTS LIMITED SALES TO INDUSTRIAL USERS
3.	MILITARY APPLICATIONS	SOME SHUTTLE-BASED MANUFACTURING, MOSTLY SPACE STATION EARLY MARKET ESTABLISHMENT
4.	PROCESS DEVELOPMENT	SPACE-STATION BASED ON-BOARD ANALYSIS SKILLED CREW REQUIRED
5.	COMMERCIAL MANUFACTURING	AUTOMATED FACILITIES SPACE STATION TENDED MATURE MARKET

SPACE-PRODUCED GaAs USER CONCERNS

A survey of potential industrial users of space-produced gallium arsenide crystals has yielded these concerns.

1. The industry has billions of dollars invested in silicon-based technology which is already profitable. It is therefore reluctant to replace that investment with a new, expensive technology.

2. Most corporate investment focuses on near-term, assured return on the investment, whereas space-based GaAs production entails considerable risk to produce long-term gain.

3. Most industrial firms interviewed expressed some reservation about investing in a program which depends on timely operations of a government-built facility. Capital investment requires a firm schedule so that appropriate captial can be raised with a known date of return. Concern was expressed that the government can maintain a firm delivery schedule in periods of budgetary constraints and changing policies.

4. For most semiconductor users, the path of least risk appears to be to let Microgravity Research Associates (MRA) take the risks. The established firms would then buy samples produced by MRA for their own characterization. Once the commercial feasibility is demonstrated, then existing companies can exploit the new technology at minimum risk with a quicker return on their investment.

Space-Produced GaAs User Concerns

- Magnitude of investment in silicon based technology

- Long period of negative cash flow

- Government commitment to firm schedule

- Minimize risk by waiting for MRA samples to characterize

SPACE STATION ATTRIBUTES FOR SEMICONDUCTORS

The most notable requirement that semiconductor processing imposes on space station design is power. To grow 20 kg of GaAs crystals per week requires between 50 and 500 amps of steady DC current, which consumes 10-20 kw of electrical power. Optimum temperature requirements are not yet known, but they are likely to be in the 850-950^{0}C range. Acceleration is a key parameter which remains to be determined. If accelerations in the neighborhood of 10^{-3}g are permitted, the growth furnace can probably be a rigidly attached part of the space station itself. If the growth process is sensitive to accelerations as low as 10^{-5}g, then free flying growth modules are more likely. For serious process development, a highly trained professional crew member (or members) with a well-equipped diagnostic laboratory is necessary.

Space Station

NASA 88-017

Space Station Attributes for Semiconductors

BOEING

• Power	~ 10 kW continuous DC
• Temperature	~ 1000°C
• Acceleration	$\lesssim 10^{-4}$ g
• Equipment	Diagnostic lab facilities
• Crew	Highly trained professional
	Free-flying factories with frequent servicing

BIOLOGICAL MATERIALS MISSIONS

A variety of biological materials processes are being considered for space station development. The process which is undoubtedly most advanced at this time is continuous flow electrophoresis, which has already been shown to be useful for separation of beta cells. Other biological materials, such as human fetal kidney cells and hormones, will also be separated. Other processes will also be considered for biological separation and purification. A more in-depth investigation of a collagen processing mission has been carried out, which might serve as a model for other processes involving orientation of fibrous materials. An interest is being developed among X-ray crystallographers and nuclear magnetic resonance spectroscopists in combining two different features of microgravity processing: the ability for high quality separation of biological materials and the ability for controlled growth of large crystals. This area holds potential for resolving the three-dimensional structure of macromolecules.

Biological Materials Missions

- Commercial electrophoresis
  - Beta cells, HFKC, hormones, enzymes, etc.
- Other cell purification products for pharmaceuticals
  - Research missions on isoelectric focusing, isotachophoresis
- Oriented fibrous materials
  - Collagen
- Research samples of biochemical crystals
  - X-Ray crystallography, NMR spectroscopy

SPACE STATION ATTRIBUTES FOR BIOLOGICALS

Some of the space station attributes required for commercial processing of biological materials are similar to those required for semiconductors, while others are not. Common factors are the need for a highly-trained professional crew and diagnostic laboratory facilities although, of course, the specific skills and equipment required are very different. It is likely that the commercial goal will be automated factories on free-flying platforms which are occasionally serviced from the space station.

The power requirements are greatly reduced for biologicals when compared with semiconductors, because of the much lower temperatures and electrical currents needed. One additional requirement for biologicals is for keeping materials refrigerated at some stage(s) of the processing and storage.

Space Station

Space Station Attributes for Biologicals

NASA BOEING
SS-014

- Low power
- Precise thermal control, with chilling
- Diagnostic lab facilities
- Highly trained professional crew
- Free-flying autonomous factories with occasional servicing

OTHER MATERIALS PROCESSING RESPONSES

Additional materials processing areas which are being investigated include metals, glasses, ceramics, and catalysts. The general state of the economy, and the demand for heavy industrial materials in particular, affect the capital which industry is willing to invest in new metals processes. This is seen even more strongly in the magnet industry: although Skylab experiments demonstrated tantalizing possibilities for new permanent magnets, the industry is currently struggling to stay in business with existing demand, and does not foresee a surge in demand for new materials.

Some interest has been noted in production of high quality glasses. This is seen as opening new possibilities for optical communications and data processing. It appears that this interest might be stimulated by a space-based containerless processing facility which demonstrates glass formation with new properties.

Space Station

Other Materials Processing Responses

NASA BOEING

SS-013

- Market factors limit metals, alloys solidification interest
- Limited commercial glass processing interest now
- Ceramics and catalysts not yet addressed

GENERAL MPS OBSERVATIONS

Although the materials processing user needs subtask is still currently in progress, a few preliminary conclusions can already be drawn. These conclusions are generally related to the early phase of development. Although the microgravity environment offers exciting materials processing possibilities, real commercial interest has been somewhat limited to date. Although this might seem disappointing at first, it should not be construed to mean the future is not bright for commercial MPS, but rather that current conditions are not yet favorable for significant investment. Current conditions in this sense include economic and technical factors. Economic factors are limiting both the availability of research investment capital and the demand for new products. Technical factors reflect the early strage of MPS development. The long time required before a return on an investment and the uncertainty of success makes MPS a risky option. The fact that strong interest exists among academic and industrial organizations for MPS specimens is seen as an indicator of future potential. It is likely that the demand for samples produced in space which can be characterized by these organizations will remain high. Once these samples are evaluated and the possibility of near-term market potential exists, it is believed that one or two commercial successes can have a dramatic impact on commercial interest in MPS. Progress in the programs of McDonnel Douglas, Johnson and Johnson and/or Microgravity Research Associates might well provide this commercial stimulus.

Space Station

General MPS Observations

NASA SS 064 BOEING

- Strong academic interest exists for MPS specimens
- Commercial interest limited to few entrepreneurs
- Economic climate restrains activities
- One or two commercial successes can have dramatic impact

INSTITUTIONAL BARRIERS TO COMSAT USE

Commercial communications satellite companies are very conservative and have a clear requirement to make a profit. The satellite systems now in operation or being developed provide the capabilities for the currently identified needs, and it is not clear that improvements that might be available because of the space station would provide increased economic growth at low enough risk. Consequently, there is no "crying need" for these improvements, indeed, there is some reticence in providing vocal support for the space station. Clearly, substantial nonrecurring investments will be required to develop and incorporate the changes necessary in communications satellites to take advantage of the station. Also, insurance requirements and contracts for system payments based on performance would be modified greatly because of the involvement or interference of many people at the space station.

The procedures and policies for using such a station must be worked out unambiguously for a commercial company to be willing to use it. Some of the concerns are listed on the accompanying chart. All of the concerns associated with commercial use of the Space Transportation System (i.e., shuttle) are greatly magnified for a space station because of its longer life, increased size and capabilities, and potential simultaneous use by many more users.

Space Station

Institutional Barriers to MPS

- The technology is not yet mature for commercialization.
  - NASA seems unable to provide precommercial R&D at adequate levels
  - High risk, long-term payoff

- There is no well-defined, constant, national space commercialization policy.
  - No commitment to a firm schedule
  - Perceived lack of government R&D commitment
  - Need to balance operations and R&D budgets
  - R&D funding fluctuations

- NASA is not organized to provide routine services to users.
  - Primarily mission-oriented
  - Impressive mission accomplishments carry limited follow-through
  - Large bureaucracy with other primary goals
  - Reluctance to yield development controls

COMMUNICATIONS MISSIONS WHICH BENEFIT FROM A SPACE STATION

Three specific types of missions are representative of communications missions which might best use a space station. The first takes advantage of the most important capability of the station—the ability to assemble or deploy very large structures. For communications satellites this opens up the possibility of antennas much larger than currently considered. Large antennas permit the use of many feeds to allow simultaneous service over many narrow beams, thus allowing a high level of frequency reuse. For example, a C-band system with 25 meter antennas (8 - 10 times current size) would be feasible in a natural evolution from today's systems. The space station would also be useful for systems using several satellites simultaneously with less than one spare-in-orbit for each satellite. The spare could be kept in orbit attached to or near the station and could be reconfigured to meet the requirements of a specific satellite when needed. Manual feed manipulation, switching, and testing at the station could simplify the design and permit rapid replacement. The third mission would not be an operational communications system, but rather the use of the station as a platform for testing new communications hardware and techniques for handling, deploying, and servicing spacecraft or their subsystems in space. This mission would naturally seem to be a NASA mission, but it might be supported by a consortium of communications satellite companies or of contractors who build the satellites. The mission could consist of fully scheduled experiments or could take advantage of launch space when available to send up individual experiments.

Space Station

Communications Missions Which Benefit From a Space Station

NASA SS-061 BOEING

- Large antenna, multi-beam communications satellites
  - Station permits use of antenna size growth >2
  - Functions include assembly, deployment, test and calibration, and in-orbit servicing
- Multi-satellite communications systems, 10 - 20 years ahead
  - Complex and expensive payloads
  - Operational/configurable differences between satellites
  - Non-interruptable service -- hence spares
  - Typical system -- 4 zone direct broadcast
- Spacecraft and communications payload hardware testing
  - Technology mission on or near station
  - Supported by NASA or consortium
  - Last minute experiments (to fill shuttle payload)

RCA Astro-Electronics

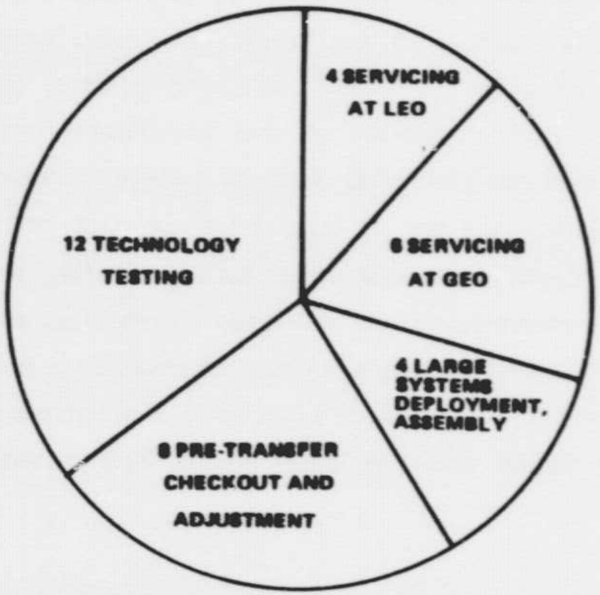
SUMMARY OF COMMUNICATIONS FUNCTIONS CONSIDERED

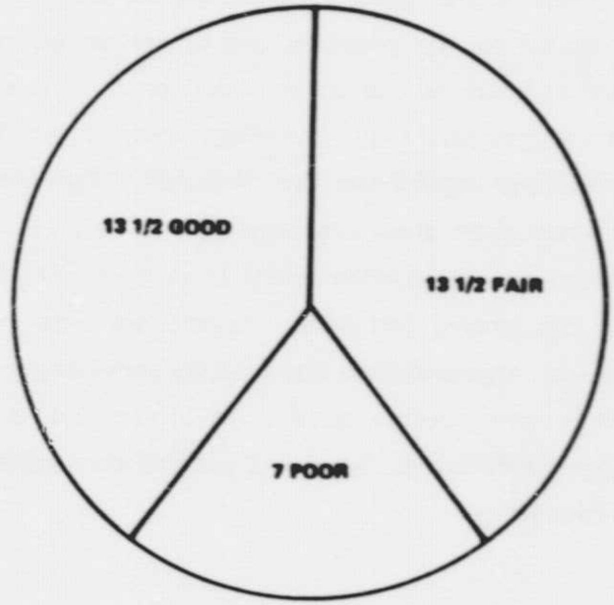
Thirty-four different functions of potential benefit to communications satellites were considered to be performed on or with the aid of a space station. The functions were reviewed with communications payload engineers, spacecraft support subsystems designers, integration and test specialists, and representatives from a common carrier company which buys and uses communications satellites. Based on this review, the functions were evaluated as Good, Fair, or Poor candidates. The numbers in each rating category and the general classification of the types of functions are shown in the "pie charts" on the accompanying figure. Those considered best are summarized by type in the listing shown. They generally relate to the new capabilities offered by the space station, rather than just the ability to do things better. Specifically important are the possibilities of being able to use very large (e.g., 25 - 40m) antennas by assembling them at the station, of being able to reconfigure the antenna of a store-in-orbit spare to tailor it to the unique pattern needs of a satellite to be replaced, or reducing weight (or allowing more weight) because of the availability of an multi-function OTV, and of long term zero-G experiments on thruster plumes and contamination, flud motions, and new handling tools and procedures.

Space Station

Summary of Communications Functions Considered

NASA SS 165 BOEING





BEST:

- LARGE ANTENNA ASSEMBLY, DEPLOYMENTS
- ZERO G TECHNOLOGY TESTING
- POST STS - LAUNCH PREPARATION
- SPARE SATELLITE RECONFIGURATION
- OTV USE FOR TRANSFER, FUELING

RCA Astro-Electronics

DESIGN IMPACTS AND REQUIRED STATION CAPABILITIES (PRELIMINARY)

The tools at the space station and the design changes for new communications satellites required to perform the functions listed on the previous charts are to be considered throughout the remainder of the study. However, some preliminary indications can be provided now. The space station would require work areas and associated utilities for individual experiments (for technology test) or for full spacecraft servicing. Both controlled remote manipulators and manual servicing capabilities are required. For the latter, on-station payload specialists as well as general support technicians would be used, probably with some EVA. Vehicles which only work near the station (e.g., a teleoperator) or to transfer to or operate at other orbits (e.g., an OTV) will certainly be required. Certainly, also storage, data monitoring and processing equipment, and other support services will be required. For the communications satellites themselves, the possibilities of large antennas and in-orbit servicing suggest changes in design to increase modularity and accessibility. Full antenna deployment before transfer to GEO would require changes to the propulsion and guidance systems to avoid stresses on the large appendages. Servicing possibilities, especially if performed on a regular schedule, could permit designs with reduced redundancy.

Space Station

Design Impacts and Required Station Capabilities (Preliminary)

NASA SS-066 BOEING

- Tools/capabilities at the space station
  - Manipulators and EVA capabilities
  - "Dry dock" stations (equipment for test, monitoring, power, etc.)
  - Experiment work stations
  - Sensors, displays, data handling systems
  - RF system test equipment, e.g., targets
  - Payload specialists
  - Orbital transfer vehicle (OTV), teleoperator
  - Fuel and component storage
- Spacecraft design concept changes
  - Modular, assembleable large antennas/structures
  - Manual switching, deploying
  - All liquid, refillable propellant tanks
  - Low G, non-spin propulsion
  - Increased accessibility, reduced redundancy

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INSTITUTIONAL BARRIERS TO MPS

Three major factors are responsible for industry's cautious approach to commercial materials processing in space.

1. Industry feels that much research needs to be done before the capabilities of MPS are demonstrated. Industry is not willing to invest in what is seen as a high risk, long term research program, and they perceive an inability for NASA to support the precommercial R&D effort that they feel is required to reduce the risk. Industry generally feels that MPS is ready for research-not for commercial investment.

2. Industry responds favorably to a firm committment which establishes a predictable schedule and the necessary resources to maintain that schedule. They are uncomfortable about working with a program which is subject to annual changes in funding levels and in direction. When industry commits its funds to a development program, it needs to be assured that the program will begin to yield a return after a definite time. There have been false starts and stops in MPS programs and delays resulting from the need to offset delays and overruns in other parts of the NASA budget. These are seen as indicative of a weak government commitment to provide the necessary R&D over the long term.

3. NASA's history is characterized by very impressive accomplishments. To achieve these goals, it is organized with an R&D mission orientation. This has enabled outstanding success in the development of spacecraft for manned and unmanned missions. Once these mission shave been accomplished, the degree of follow-through has been less impressive. NASA seems to focus on achieving success in advanced technology missions and to be organized with these primary goals. To an industrial firm interested in establishing a small program, it is difficult to learn where to interact with NASA and unsettling to feel that other mission have much higher priority.

Space Station

Institutional Barriers to COMSAT Use

NASA SS 066

- Uncertain economic return from the improved systems
  - No urgent need for the improved capabilities now
  - Capital investment channeled to near-term gain
  - Advanced concepts seen as high risk
- Ambiguous government policies:
  - Availability of space station
  - Priorities and schedules
  - Use of government or industrial employees for on-board activities
  - Safety and industrial security protection
  - Commitments to permanently maintain an operational station
  - Unknown regulations and policies

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Technology Demonstration Missions

TECHNOLOGY DEVELOPMENT MISSIONS

The chart on the facing page is self explanatory.

Space Station

Technology Development Missions

NASA 88-048 BOEING

- Contacted NASA Staff
- Reviewed literature
- Identifying experiment needs
- Defined scheduling rationale
- Continuing tasks
  - Identification of additional TD missions
  - Scheduling of all experiments
  - Integration of experiments with design

CANDIDATE TECHNOLOGY DEVELOPMENT MISSIONS

This chart shows the breakdown of technology development missions by disciplines. Each discipline is represented by its percent of the total 47 technology development experiments. Contacts with individual experts and authorities on each experiment have yielded sparce results.

The shaded areas indicate what percent of each discipline on which we have currently been able to gather additional experiment data.

The discipline of communications and tracking has provided the largest amount of data to date.

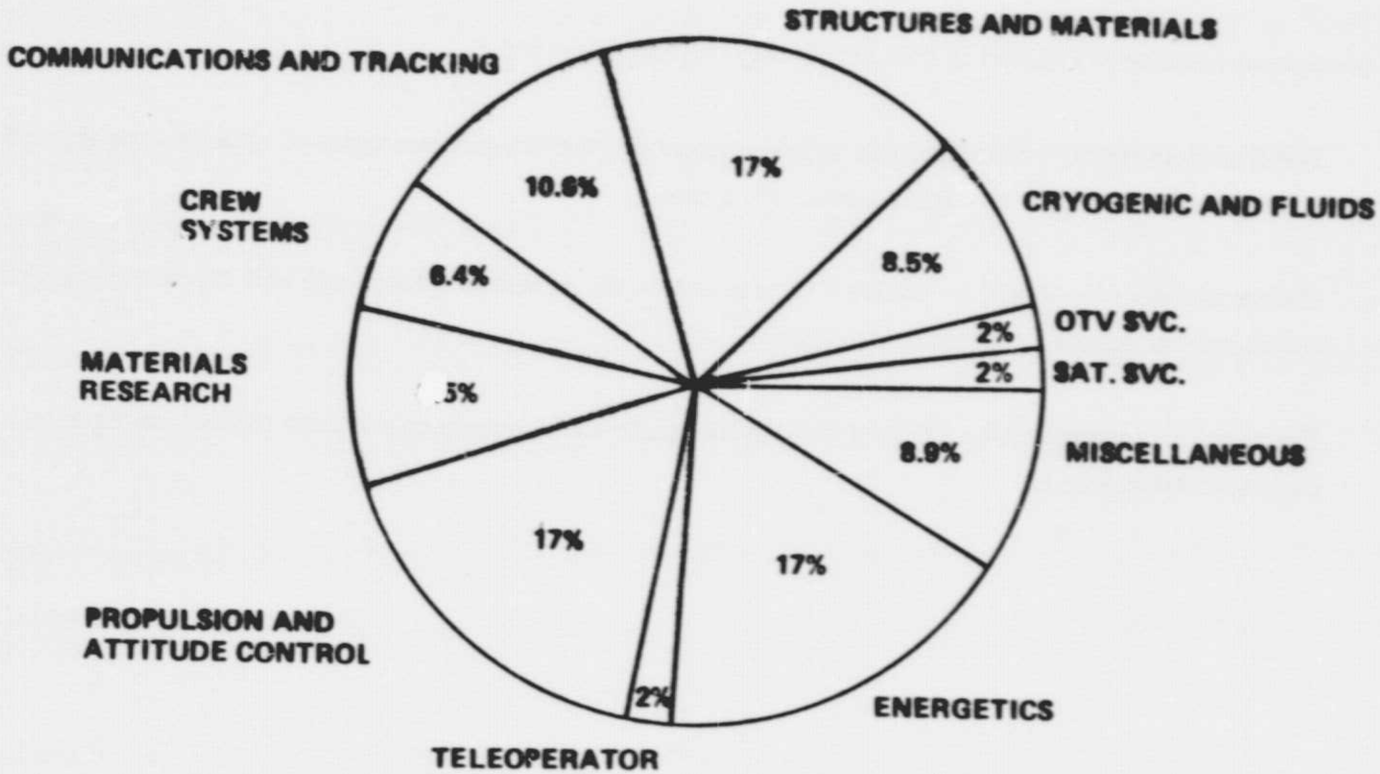
A total oi 23% of the technology development experiements have provided additional inputs.

Space Station

NASA

Candidate Technology Development Missions

BOEING



REVIEW OF RELATED TECHNOLOGY DEVELOPMENT STUDIES

In order to minimize d[illegible] effort, a literature search is being conducted to identify sources of relevent technology development mission [illegible]

Several documents have been utilized in this technology development task:

- o The first document, was utilized to define and catagorize the various types of experiments and integration of requirements within an experimental discipline.

- o The second document will be utilized to help define the scheduling rationale and the integration of experimental requirements across experiment disciplines.

- o The third document will be utilized to help integrate the requirements across mission categories (i.e., commercial, scientific, etc.).

Space Station

NASA

SS 052

Review of Related Technology Development Studies

BOEING

- Reference Earth Orbital Research and Applications Investigations (Blue Book, NNB 7150.1, NASA, January 1971)
    - Means of defining and categorizing various types of experiments
- Shuttle Launched Modular Space Station Contract NAS 9-9953, North American Rockwell, January 1971
    - Experiment scheduling rationale
- Manned Orbital Systems Concepts Study Contract NAS 8-31014, McDonald Douglas Astronautics Company, 30 September 1975
    - Identification of candidate experiment payload and mission requirements

EMERGING EXPERIMENT REQUIREMENTS

We will continue contracts with individual experts and authorities to identify specific technology development experiment requirements. At this time (as was pointed out in the previous chart) many of the experiments are not well defined or have much hard data identifying specific requirements. We are going to have an ongoing effort to shake out these requirements.

Space Station

Emerging Experiment Requirements

NASA 88-050 BOEING

- Dedicated laboratory facilities
  - Laser
  - Cryogenics
  - Crystal growth
  - Tether/free flyer
    - Long term cryogenic fluid storage technology
    - Electronic materials processing
    - Large antenna development
    - Controlled acceleration propulsion
    - Attitude control
      - Adaptive control experiment
      - System identification experiment
- General purpose laboratory facilities
  - Personnel wish to conduct experiments on off time
  - Crew systems research and exercise facility
  - Instrumentation
- Dedicated process control computers
  - Cryogenics
- Flexible data processing computers
- EVA – MMU
  - Large structures technology experiments
  - Antenna deployment and adjustment
- Trained scientists

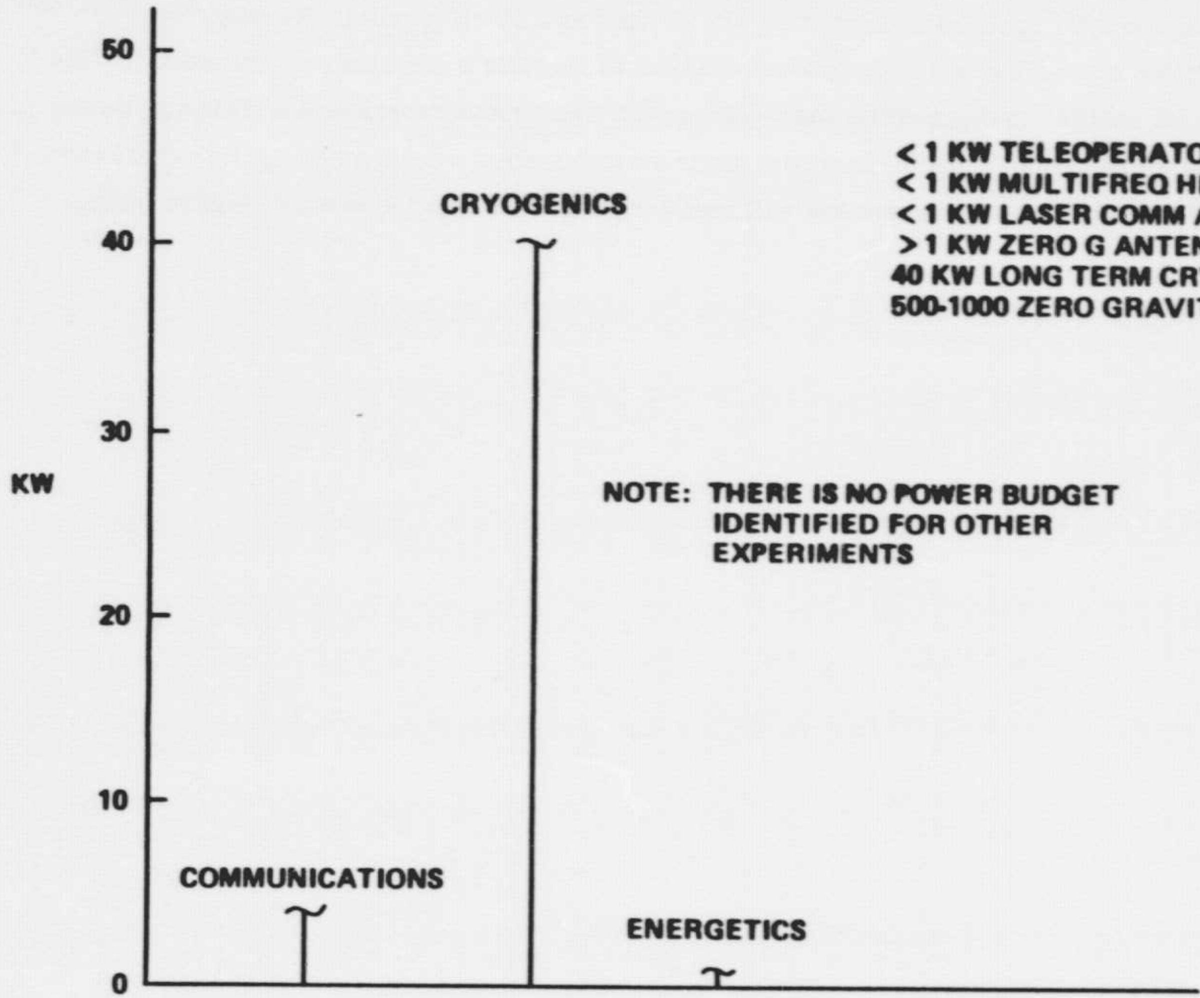
ELECTRICAL POWER

This chart shows that the power requirements are not really well defined. The data only provides generalities such as less than or more than without duration, etc.

Space Station

Electrical Power

NASA SS-038 BOEING



< 1 KW TELEOPERATOR
< 1 KW MULTIFREQ HIGH IN ANTENNA
< 1 KW LASER COMM AND TRACKING
> 1 KW ZERO G ANTENNA RANGE COMM
40 KW LONG TERM CRYOGENIC FLUID STORAGE
500-1000 ZERO GRAVITY BROMINE PHASE SEPARATION

NOTE: THERE IS NO POWER BUDGET IDENTIFIED FOR OTHER EXPERIMENTS

EXPERIMENT SCHEDULING

The scheduling rationale developed in the 1971 space station studies will be used as a starting point. We will continue the effort to categorize experiments for scheduling and then conduct analysis of feasible experiment combinations. This analysis will drive out requirements for station configurations that will support the various experiments. This will be an iterative process to arrive at a satisfactory blend of demands on the space station system versus meeting the experimenter's appetites. The resulting technology development experiment set will then be integrated into the overall mission model.

Space Station

Experiment Scheduling

NASA BOEING

86-027

- Facilities, subsystems, crew and resources available at each plateau will be evaluated to determine level of experiments that can be accomplished.
- Experiment schedule will be evolved based on station capability, experiment categories, commonaltiy of equipment, and cost od equipment.
- Scheduling Criteria
  - High benefit experiments early in program
  - Precursor experiments must be accomplished early in program
  - Experiments that utilize common equipment or personnel should be schedule together
  - Resource availability

Space Operations Missions

FLIGHT SUPPORT OPERATIONS: HERITAGE FROM SOC STUDIES

In our Space Operations Center studies, flight support operations were extensively analyzed. Many of the products, of this analysis will be usable in this study as the basic assumptions and ground rules are the same.

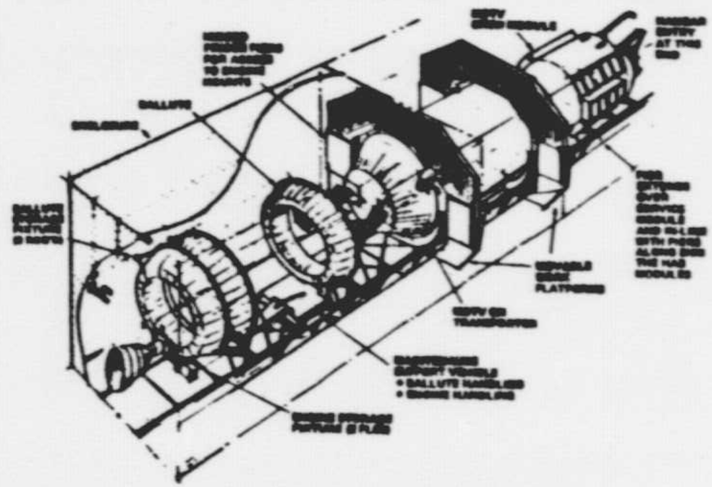
In the SOC study, we developed low, median, and high flight support mission models that were based on planning data, literature, and cost analyses. The mission models were analyzed to define time-phased shuttle manifests, OTV operations, propellant deliveries, and TMS operations.

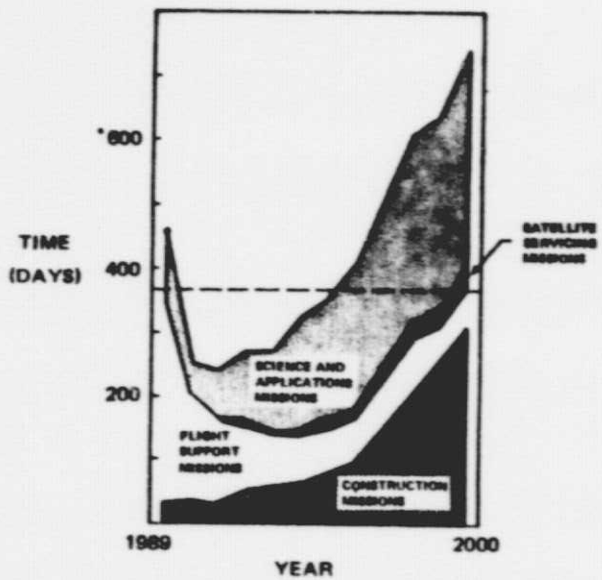
The flight support analyses included detailed operations analyses for each of the vehicles shown on the facing chart. Further information on these operations analyses are given in the following charts.

Space Station

Flight Support Operations: Heritage From SOC Studies

NASA SS-140 BOEING





- DEFINED FLIGHT SUPPORT MISSION MODELS
  - LOW, MEDIAN, HIGH
  - DERIVED FROM
    - COST CONSTRAINED MISSION MODELS BASED ON PLANNING DATA, LITERATURE, AND COST ANALYSES
    - OPERATIONS COST TRADES
- DEFINED TIME-PHASED CONCEPTS FOR FLIGHT SUPPORT FACILITIES, SUPPORT EQUIPMENT, CREW, AND OPERATIONS ASSOCIATED WITH:
  - ORBITER
  - GROUND-BASED OTV
  - SPACE-BASED OTV
    - UNMANNED
    - MANNED
    - 2-STAGE
    - 1 1/2-STAGE
    - AEROBRAKED
    - NON-AEROBRAKED
  - TELEOPERATOR
  - SHUTTLE-DERIVED VEHICLES
- DEFINED RELATIVE COSTS OF VARIOUS OTV OPERATING MODES

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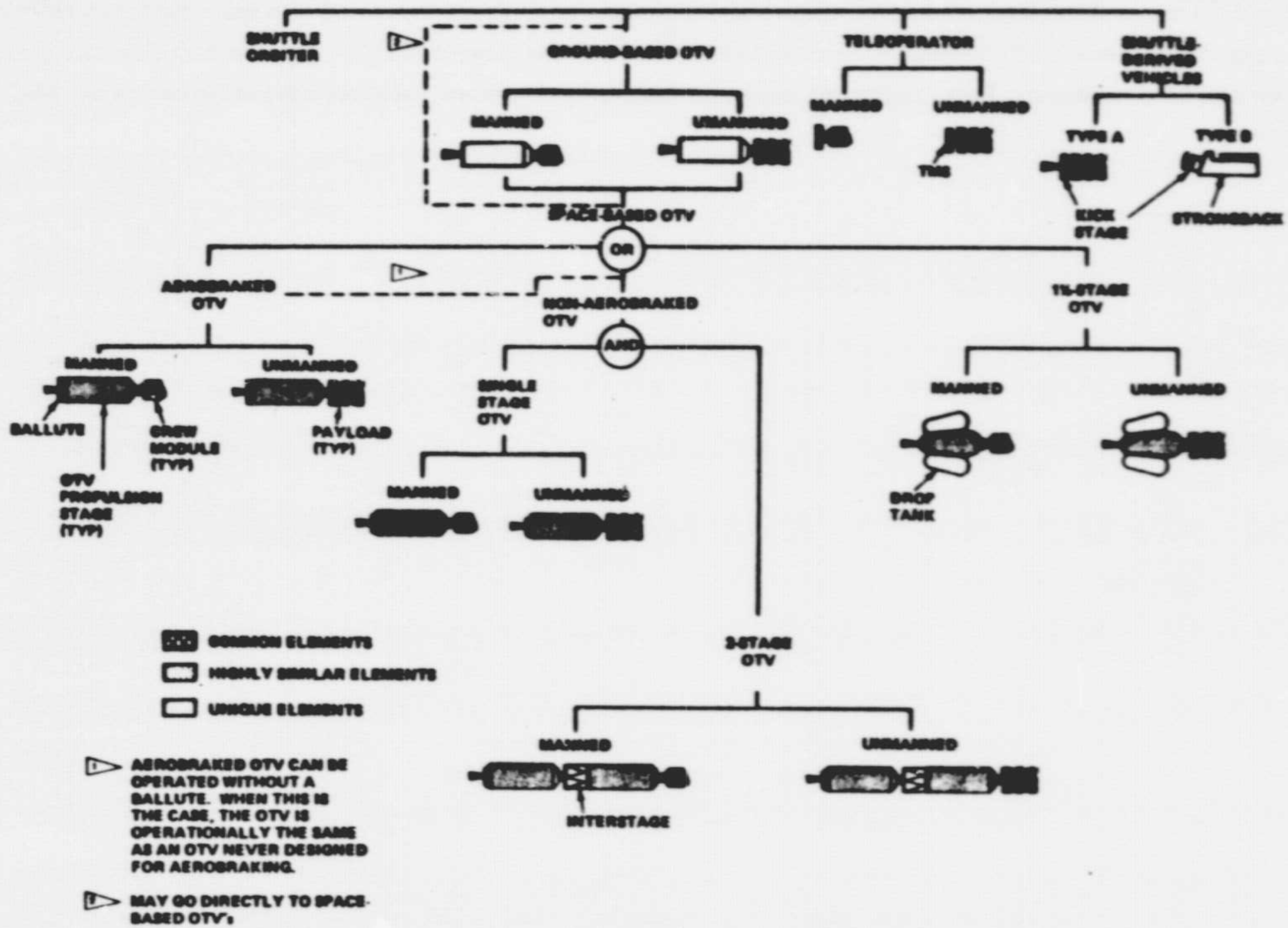
TYPES OF SPACE VEHICLES INTERFACING WITH SOC

The facing chart shows the spectrum of space vehicles that will interface witha space station. With the possible exceptions of the 1 1/2-Stage OTV and the shuttle-derived vehicle, all of these vehicle types will need to be considered in this current space station study.

Space Station

Types of Space Vehicles Interfacing With SOC

NASA SS 144 BOEING



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SOC FACILITIES, MODULES AND EQUIPMENT APPLICABLE TO VARIOUS SPACE VEHICLES

The facing chart shows the results of our SOC flight support operations analyses translated into space station requirements. We would expect that most of these requirements will still be valid in the current study as they are based on the same vehicles we will be considering. These equipment and facilitization concepts are based on trades reported in our SOC documentation.

Space Station

SOC Facilities, Modules, and Equipment Applicable to Various Space Vehicles

NASA SS-143 BOEING

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VEHICLE \ FACILITIES/MODULES/SUPPORT EQUIP. REQ'D		SERVICE MODULE DOCKING PORTS	DOCKING TUNNEL DOCKING PORTS	HANGAR NO MAINT PROVISIONS	HANGAR MAINT PROVISIONS	TRACK NETWORK OPERATIONAL SOC	GROWTH SOC CONFIGURATION	GROWTH SOC CONFIGURATION WITH ADDITIONS	GROWTH SOC CONFIGURATION PLUS ANOTHER DOCKING TUNNEL	VEHICLE/MODULE TRANSPORTERS	UMBILICAL SYSTEM IN HANGAR	UMBILICAL SYSTEM ON PIER	STORAGE FACILITY PLATFORM AREA	EXPANDED PLATFORM AREA	PAYLOAD STORAGE AREA	PROPELLANT STORAGE/TRANSFER SYSTEM	AIRLOCK MODULES AM-1	AIRLOCK MODULES AM-2	PORTABLE IVA TUNNEL	MOBILE CHERRYPICKER AND HANDLING TOOLS	BALLUTE/ENGINE TRANSPORTER	CREW MODULE
ORBITER		•	•			•	•								•					•		
TELEOPERATOR	– UNMANNED					•	•			•		•			•					•		
	– MANNED						•			•		•			•					•		•
GROUND-BASED OTV	– UNMANNED			•		•				•		•			•					•		
	– MANNED			•			•			•		•			•		•	•	•	•		•
AEROBRAKED OTV	– UNMANNED				•	•	•			•	•	•	•		•	•				•	•	
	– MANNED				•		•			•	•	•	•		•	•	•	•	•	•	•	•
SINGLE STAGE OTV	– UNMANNED				•	•	•			•	•	•	•		•	•				•	△2	
	– MANNED				•		•			•	•	•	•		•	•	•	•	•	•	△2	•
2-STAGE OTV	– UNMANNED				•	•	•			•	•	•	•		•	•				•	△2	
	– MANNED				•		•			•	•	•	•		•	•	•	•	•	•	△2	•
1½-STAGE OTV	– UNMANNED				•	•	•		• △1	•	•	•	•		•	•				•	△2	
	– MANNED				•		•		• △1	•	•	•	•		•	•	•	•	•	•	△2	•
SHUTTLE DERIVED VEHICLE	– TYPE A							•						•	•					•		
	– TYPE B							•						•	•					•		

△1 REQ'D FOR 3 AND 4 DROP TANK VERSIONS ONLY

△2 TRANSPORTER CONFIGURED FOR ENGINE HANDLING ONLY

CONSTRUCTION OPERATIONS: HERITAGE FROM SOC STUDIES

In our Space Operation Center studies, construction operations were extensively analyzed. Many of the products of this analysis will be usable in this study as the basic assumptions and ground rules are the same.

In the SOC study, we developed low, median, and high construction mission models that were based on planning data, literature, and cost analyses. These mission models were used to define the time-phased construction operations.

We performed detailed analyses of the construction operations associated with the four representative spacecraft listed (also refer to next chart). We compared the construction operations for the SOC with those that would be required on the orbiter.

We also defined the construction operations associated with assembling the SOC.

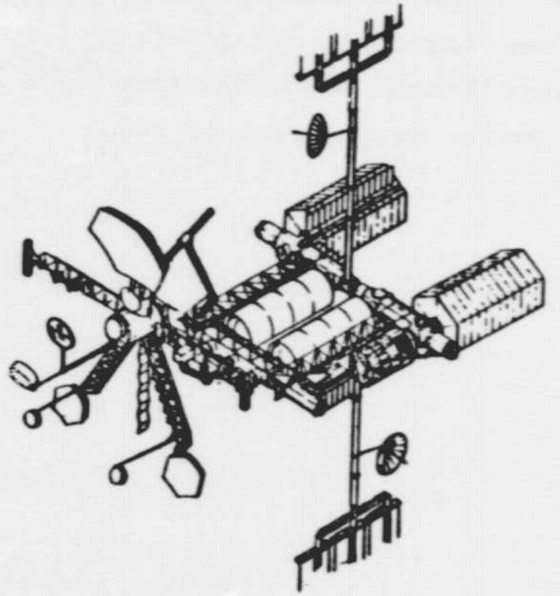
Space Station

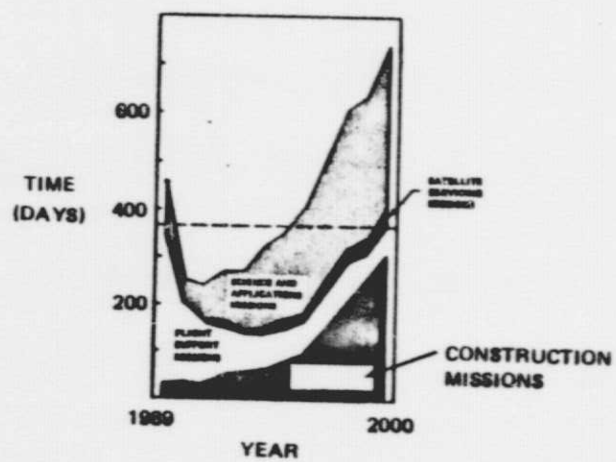
NASA

SS-140

Construction Operations: Heritage From SOC Studies

BOEING





- DEFINED TIME PHASED CONCEPTS FOR CONSTRUCTION FACILITIES, SUPPORT EQUIPMENT, CREW, AND OPERATIONS ASSOCIATED WITH:
  - EXPERIMENTAL GEO COMMUNICATIONS PLATFORM
  - LARGE AMBIENT IR TELESCOPE
  - ORBITING DEEP SPACE RELAY STATION
  - ENGINEERING VERIFICATION TEST ARTICLE
- DEFINED CONSTRUCTION MISSION MODELS
  - LOW, MEDIUM, HIGH
- DEFINED CONSTRUCTION OPERATIONS AND EQUIPMENT REQUIRED FOR SPACE STATION BUILDUP
- COMPARE SPACE STATION CONSTRUCTION OPS TO ORBITER-BASED CONSTRUCTION OPS

CONSTRUCTION PROJECTS SUMMARY

The facing chart gives a high-level summary of the results of the construction analyses. The four representative spacecraft ranged from a deployable communications satellite to a huge spacecraft that required beam fabrication. The operations analyses included timeline analyses that showed construction times ranging from 8 days to 59 days. The available crew size was a given, either 4 or 8. Detailed lists of support equipment and facilities requirements are available in the SOIC final reports.

Space Station

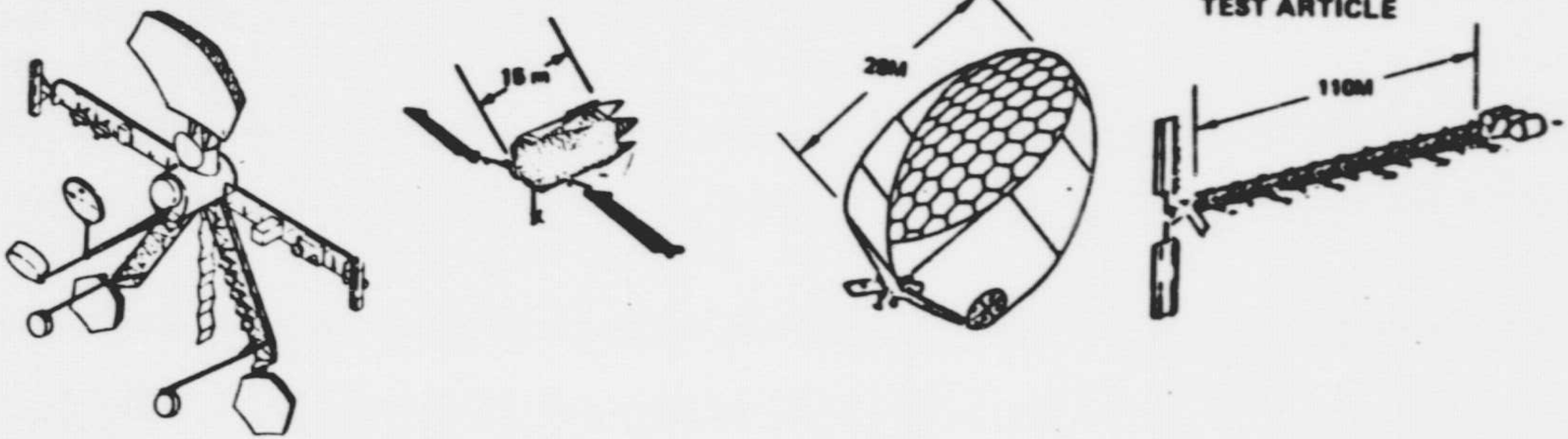
Construction Projects Summary

NASA 86-146 — BOEING

PROJECT TIME, DAYS

0 — 10 — 20 — 30 — 40 — 60

	EXPERIMENTAL GEO COMM PLATFORM	LARGE AMBIENT IR TELESCOPE	ORBITING DEEP SPACE RELAY STATION	ROCKWELL ENGINEERING VERIFICATION TEST ARTICLE
	DEPLOY TEST MATE TO OTV LAUNCH	ASSEMBLE & DEPLOY TEST MATE TO OTV LAUNCH	ASSEMBLE & DEPLOY TEST MATE TO OTV LAUNCH	FABRICATE & DEPLOY ASSEMBLE TEST MATE TO OTV'S LAUNCH
NO. OF ORBITER FLTS	2	2	2	4
SOC CREW SIZE	4	8	8	8



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CONSTRUCTION FACILITY—WHAT WE HAVE LEARNED

The facing chart summarizes the most significant findings from our construction analyses. These lessons should be generally applicable to this current space station study.

Space Station

Construction Facility
- What We Have Learned -

NASA 88-006

BOEING

- Initial SOC construction operations limited to simple appendage deployment
- Operational SOC construction operations can include assembly of components
- Growth SOC construction operations can include fabrication of structure
- EVA is preferred approach – automation not practical
- Testing operations may take more time than construction operations (need to analyze test requirements in more detail)
- Construction time paced by cherrypicker operations
- Portable EVA workstation one of keys to productivity
- Need on-board storable locations to minimize orbiter staytime
- Multipurpose positioning fixtures are essential

SATELLITE SERVICING OPERATIONS: HERTAGE FROM SOC STUDIES

In the Space Operations Studies, satellite servicing operations were extensively analyzed. Many of the products of this anlaysis will be usable in this study as the basic assumptions and ground rules are the same.

In the SOC study, we devleoped low, median, and high satellite mission models based on planning data, literature, and cost analyses. These mission models were used to define the time-phased satellite servicing operations.

We performed a detailed analysis of the servicing operations associated with the AXAF spacecraft. Facilities, support equipment, crew skills, and operations were defined. A comparison was made to performing the same servicing from the orbiter.

Satellite servicing costs were analyzed and compared to Orbiter-based costs.

We also made a detailed comparison of satellite servicing and construction support equipment to identify common requirements. These requirements were compared to the equipment being stated for use of the Orbiter.

We also investigated formation flying strategies. The following charts discuss this in detail.

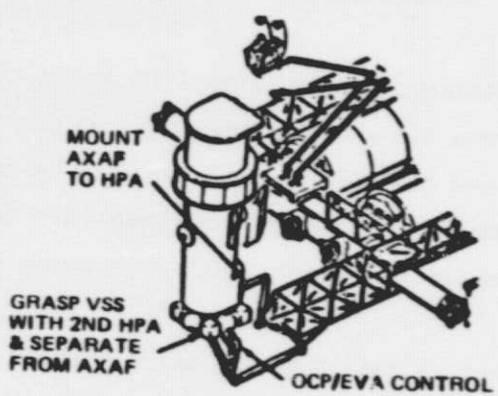
Space Station

NASA

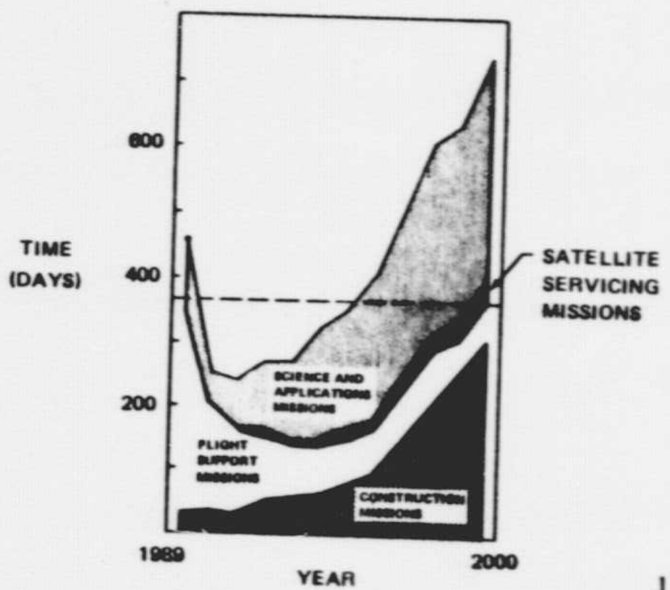
86-147

Satellite Servicing Operations: Heritage From SOC Studies

BOEING



SERVICING PREPARATION



- DEFINED TIME-PHASED CONCEPTS FOR SATELLITE SERVICING FACILITIES, SUPPORT EQUIPMENT, CREW AND OPERATIONS ASSOCIATED WITH:
  - ADVANCED X-RAY ASTRONOMY FACILITY
- DEFINED SATELLITE SERVICING MISSION MODELS
  - LOW, MEDIAN, HIGH
- COMPARED SPACE STATION SAT SERVICING OPS TO ORBITER-BASED SAT SERVICING OPS
- COMPARED SATELLITE SERVICING COSTS (SPACE STATION VERSUS ORBITER)
- COMPARED SATELLITE SERVICING AND CONSTRUCTION SUPPORT EQUIPMENT REQUIREMENTS
- DEFINED FORMATION FLYING STRATEGIES

FORMATION FLYING

Formation flying occurs when two or more payloads maintain position relative to one another within specified limits. There are several categories of formation flying. They are distinguished by what relationship the payloads maintain. Here the particular case is an unmanned platform which maintains position relative to a space station.

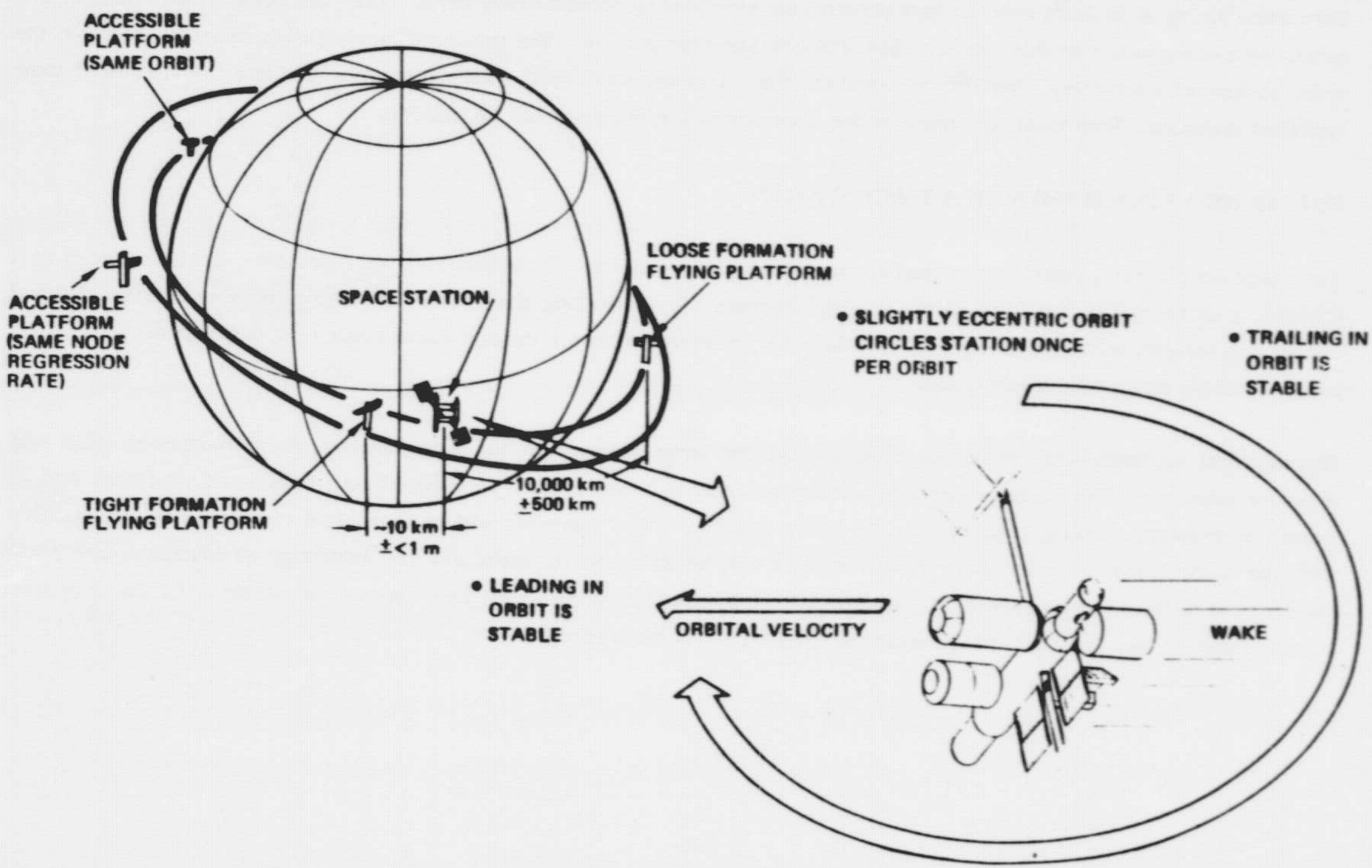
The only position for a platform that remains fixed relative to the space station is in the same orbit as the station, either ahead or behind it. If there are a number of payloads which need to be near the station, they can be in slightly eccentric orbits which appear to circle the station once per orbit. The range of these co-orbiting platforms may be from 10km to 10,000km, the longer distances being out of direct line-of-sight. The position tolerance may range from fractions of a meter, as in astronomical interferometry, to hundreds of kilometers for a platform that only needs to be easily accessible.

Another category of formation flying is when a platform is at a different altitude than the space station, but the node regression rate is such that the platform is accessible. Either the node regression rate is the same or there is a large difference between the rates. In either case opportunities to reach the platform with a small delta V exist.

Space Station

Formation Flying

NASA 86-186 BOEING



FORMATION FLYING: USES

PRESENT USES

Formation flying is de facto used by communications satellites in geostationary orbit. They are assigned locations in this orbit. As a consequence of this they maintain fixed relative separations. The tolerance in position is relatively high, on the order of tens of kilometers. Navigation satellites (for example, NAVSTAR) maintain position within a few meters of their specified locations. They must stay there or the accuracy of the system would be reduced.

FUTURE USES ASSOCIATED WITH A SPACE STATION

The space environment itself is the reason many payloads are flown. Unfortunately, while providing useful services to a payload, a space station can disturb the payload in many ways. Among these are: induced gravity, vibration, thermal cycles, gas release, and electromagnetic interference. In order to benefit from a space station but not be disturbed by it, a payload can fly separately in formation.

Astronomical payloads will require carefully controlled large separations for long baseline interfereometry. For long exposure times with high spatial resolution instruments, payloads will require pointing without significant vibration, such as caused by crewmen moving about inside the space station. Other payloads will have pointing requirements incompatible with the space station. Space environment sensors will be affected by space station shadowing of particles, and earth environment sensors can be affected by gasses emitted by the station during attitude control maneuvers or EVA's. Any time a Shuttle approaches, the contamination problem will be much more severe.

Formation Flying: USES

- Present
  - Communications satellites
  - Navigation satellites
- Future
  - Astronomical
  - Space environment sensing
  - Earth environment sensing
  - Material processing

FORMATION FLYING: DRAG EFFECTS

The small amount of atmosphere still present at several hundred kilometers altitude has appreciable effects. For example, a space station at 370km with 800 m^2 of solar arrays which does not correct for drag effects will typically lose .25 km of altitude the first day, and increasing amounts on succeeding days. The magnitude of the effect depends on the ratio of satellite area to weight.

Because the earth is oblate, the mass around the equator in excess of a spherical earth shifts the plane of most orbits. As a satellite approaches the equator from the north it is pulled southward by the equatorial bulge. Once past the equator it is pulled northward. The net effect is to shift the node, the place where the satellite crosses the equator, westward. The nodes of satellites at different altitude shift at different rates. Thus a consequence of altitude loss due to drag is that the orbits get out of plane with one another.

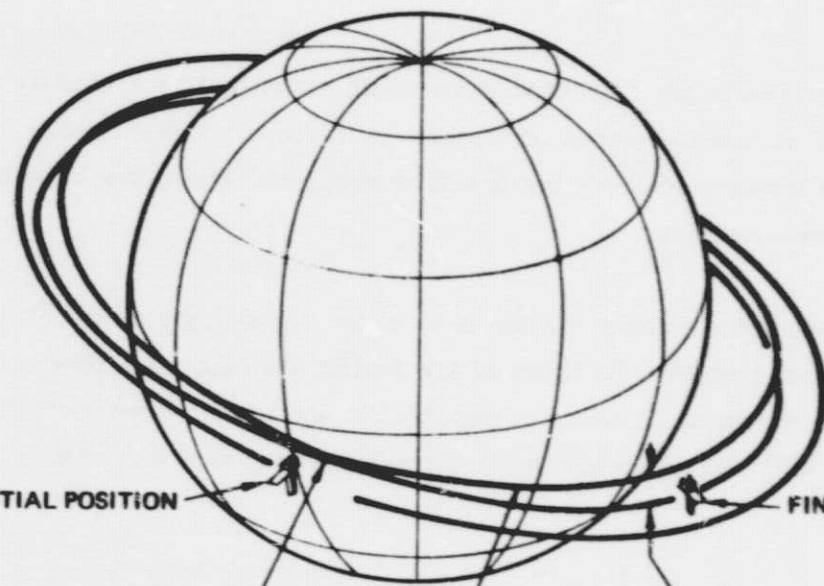
Lower altitude orbits also have a shorter period. Thus another consequence is that a platform uncorrected for drag will pull ahead of a corrected space station. The velocity charge required for access increases with these three types of orbit changes: altitude loss, plane change, and orbit phase. The change is not linear with time.

Space Station

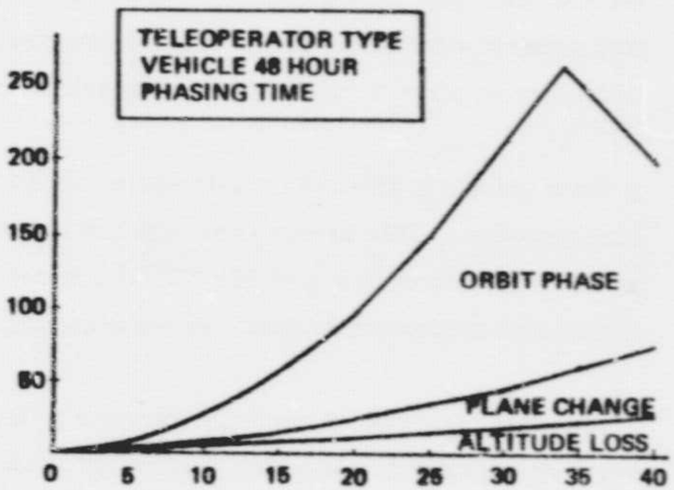
Formation Flying: Drag Effects

NASA SS 170 BOEING

• DIFFERENTIAL DRAG EFFECTS



• VELOCITY REQUIRED FOR ACCESS



FORMATION FLYING: STRATEGIES

Single burn maneuvers, which actually consist of two or more propulsive burns within an hour, are preferred for observations or experiments that require long periods without disturbance. One option is to make the corrective maneuver about halfway through the free-flying period. The platform would go to a higher orbit than the station and continue drifting downward to meet it. The orbit changes caused by atmospheric drag are largely reversed in the second half of the period. The mission is divided into two usable periods interrupt by the maneuver. To make this strategy work as well as possible, the future atmospheric conditions would have to be predicted for the second half of the mission. Otherwise, corrective burns are necessary to correct for dispersions caused by atmospheric variability.

If the platform is allowed to drift one full orbit behind, a single, larger corrective burn would return it to the vicinity of the space station. This would allow uninterrupted operation for several weeks or longer. If the separation tolerance is very small or extremely low g levels (10^{-6}g) are required, then frequent muitiple burns will be required. These should be largely automated to prevent an undue increase in space station crew workload.

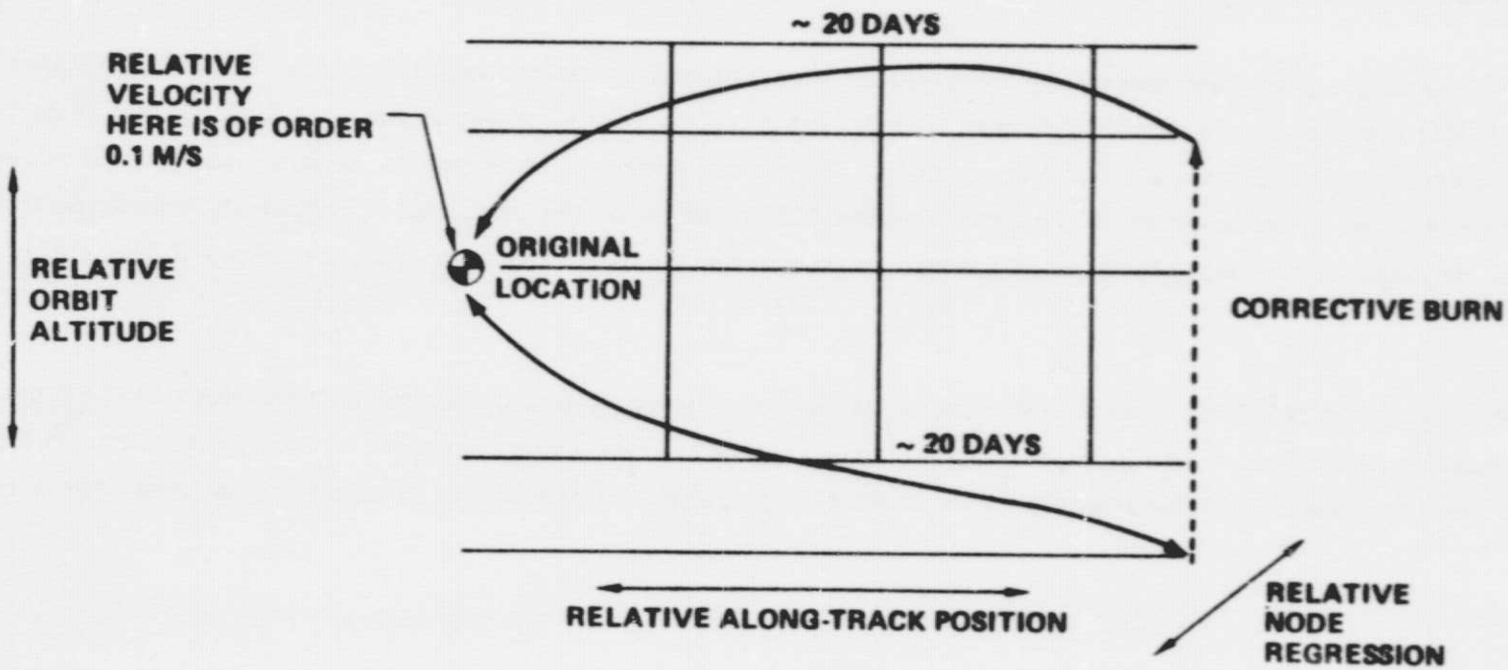
A proposed strategy to minimize transportation requirements for a space station is to allow the altitude of the station to vary with traffic levels to the station and changes in the atmosphere. At times of low traffic and high atmospheric density the station would fly higher to minimize drag makeup requirements. At times of high traffic and low atmospheric density it would be lower to minimize launch vehicle requirements. This strategy would make formation flying very difficult.

Space Station

Formation Flying: Strategies

Differential Drag Orbit Makeup

NASA 86 084 BOEING



FORMATION FLYING: DRAG MAKEUP STRATEGIES

Since many of the disturbances to a payload are due to propulsion related causes, the method of orbit correction must be chosen with care. Above 1000 km altitude, the momentum change which can be derived from reflected sunlight exceeds the amount caused by drag of the same surface. For missions longer than one year, the total impulse from reflected sunlight can exceed the impulse from a monopropellant RCS system with the same mass.

Instead of placing a propulsion system on every platform or payload, an alternative is to use a Teleoperator Maneuvering System (TMS) type vehicle to provide reboost. The advantage of this is lower development and production costs for the platform, decreased platform weight and complexity. The corresponding disadvantage is the increased propellant usage by the TMS compared to an on-platform system since the TMS must go to the platform and return as well as perform the reboost. It might be necessary because of payload contamination requirements to provide a cold gas RCS system for the TMS.

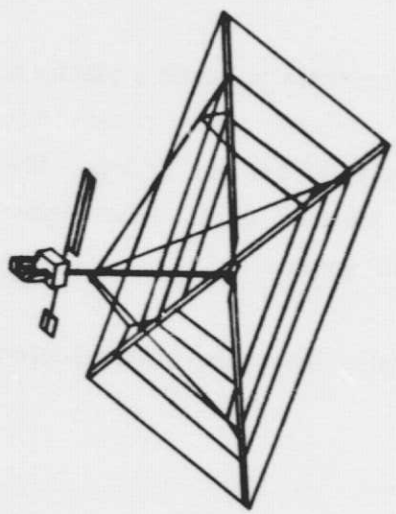
In order to trade the relative values of TMS type or on-platform type propulsion, additional utility which can be provided by a TMS must be considered. These include (relatively rapid) manned or unmanned changeout of faulty equipment on location, and because there would likely be multiple TMS's on orbit, high probability of retrieval in case of major breakdown.

Space Station

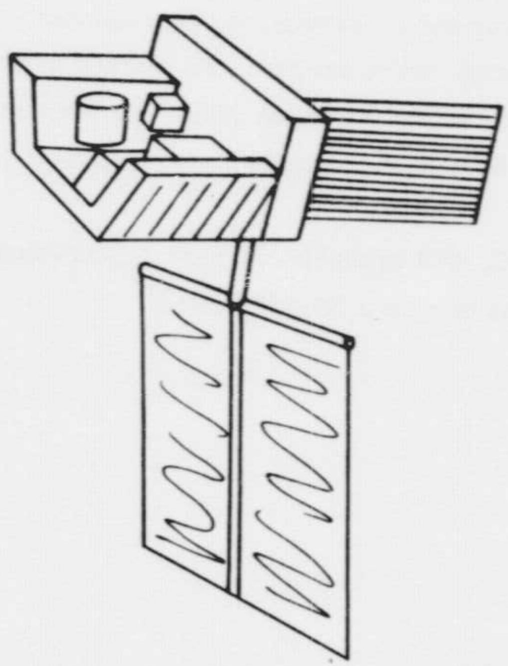
Formation Flying: Strategies for Drag Makeup Propulsion

NASA BOEING

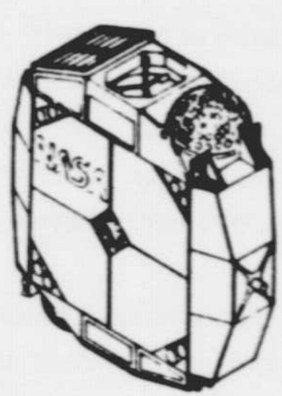
- NON PROPULSIVE (SOLAR SAIL – HIGH ORBITS)



- ON PLATFORM



- REMOTE (TMS)



FORMATION FLYING: ACCESSIBLE ORBITS

For a number of operational reasons, a satellite may not want to fly in the same orbit as a space station. In this case the orbit inclination of a platform can be selected to minimize the velocity change required to reach it. A typical space station orbit is at 370km altitude and $28\frac{1}{2}^{o}$ inclination. The equatorial crossing points, or nodes, of this orbit moves 7.2^{o} per day. The inclination of orbits up to 500km in altitude can be selected to produce the same rate of nodal regression.

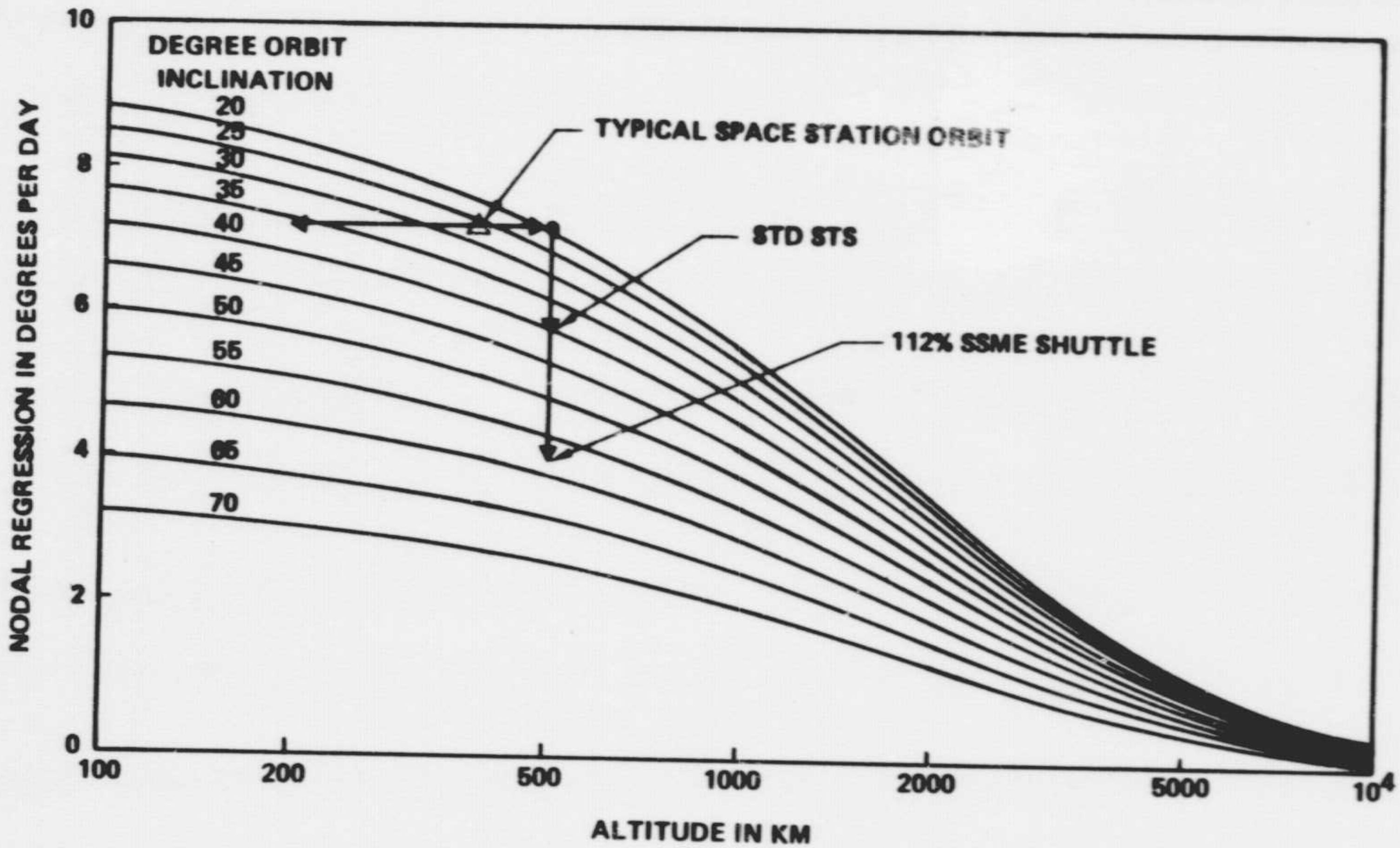
If the orbit planes are originally co-incident, then they will stay that way. The velocity requirements to reach a platform than are relatively low, a few thousand meters per second rather than five thousand for orbits completely out of phase. For higher orbits, you would switch to high inclination orbits which would regress much more slowly, 4^{o} per day or less. The difference in regression rates would cause the orbits to be in phase approximately every hundred days. The higher inclination would require a higher performance Shuttle, for example, able to deliver 65k lbs to 58^{o} inclination.

Satellites of this nature, if serviced from SOC, will probably have to be serviced on scheduled intervals. Unscheduled servicing for such satellites will almost certainly require a Shuttle flight.

Space Station

Formation Flying: Accessible Orbits

NASA SS-066 BOEING



INTEGRATED OPERATIONS ANALYSES: HERITAGE FROM SOC STUDIES

The SOC analyses found that the projected mission imposed requirements for facilities and support equipment that exceeded the projected funding capability. We did not have an opportunity to reconcile these differences in the SOC study. The current space station study must focus on resolving these incompatibilities.

Space Station

Integrated Operations Analyses: Heritage from SOC Studies

- Mission models derived from budget constraint considerations
- Integrated facilities and equipment requirements were derived
- Integrated mission requirements resulted in budget requirements that exceed realistic SOC funding profile
- Current space station studies need to focus on resolving this incompatibility between mission needs and projected space station funding limitations

CONTINUING TASKS

We will continue our search for additional technology development experiments through:

- o Extensive literature searches to identify new areas of research and locate all available data on already identified experiments.

- o Further contract with NASA staff, industry, and academic community to develop additional information.

Effort will be made to give priority scheduling to high benefit and precursor experiments.

As experiment requirements emerge from detailed analysis they will be coordinated with design to facilitate design of optimum space station.

Space Station

Continuing Tasks

NASA 86-020 BOEING

- Identification of Additional Missions
  - Literature search
  - Contact with NASA, industry, and universities
- Scheduling of All Missions
  - Science and applications
  - Commercial
  - National security missions
  - Technology development experiments
- Integration of Mission Requirements with Station Design
  - Identify and integrate all requirements
  - Coordinate requirements with detail design

Space Station

Topics of Interest

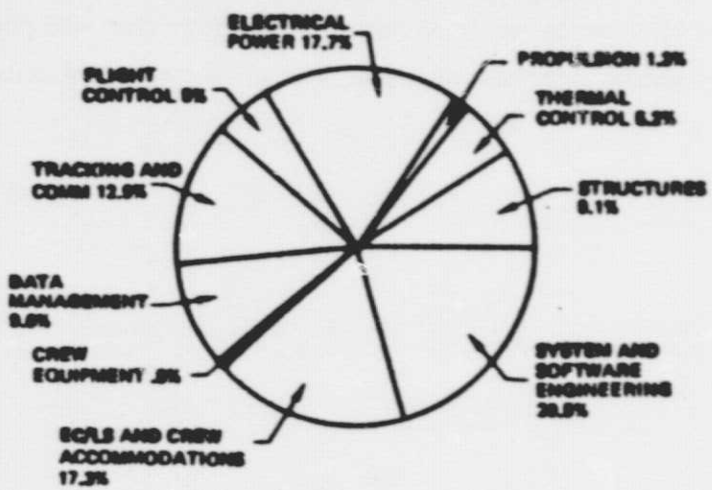
NASA — BOEING

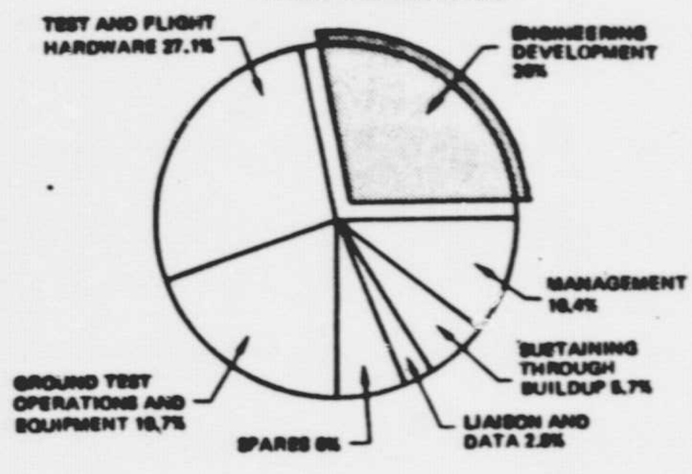
- Cost drivers
- Technology drivers
- Integrated O_2 - H_2 systems
- Human factors and man-machine interface
- Application of artificial intelligence to space station
- Architectural trades and definition approach
- Making the station user friendly

Cost Drivers

Significant program cost drivers are summarized on the facing page.

Cost Drivers





- MAIN SUBSYSTEM COSTS ARE EC/LS; DATA MANAGEMENT; ELECTRIC POWER; AND COMMUNICATIONS.
- PROGRAMMATICS OVERSHADOW SUBSYSTEMS DESIGN AND DEVELOPMENT.
- MISSIONS AND MISSION INTEGRATION EASY TO OVERLOOK, BUT PROBABLY ABOUT EQUAL SPACE STATION FACILITY COSTS.
- "REQUIREMENTS AREN'T. THEY ARE DESIREMENTS." H. H. KOELLE, ABOUT 20 YEARS AGO. WHAT ARE WE ACCEPTING AS REQUIREMENTS; WHY; AND WHAT ARE WE PAYING?
- PARTS STANDARDS AND OTHER ARCANE DETAILS CAN OBLITERATE A BUDGET PLAN.
- MANAGEMENT ASSUMPTIONS. ESPECIALLY ASSUMING SOMETHING IS SIMPLE AND STRAIGHT FORWARD WHEN IT IS COMPLEX AND DIFFICULT. ORGANIZATION UNPREPARED TO DEAL WITH TOUGH PROBLEMS.
- INADEQUATE DEFINITION AND POORLY THOUGHT-OUT PLANNING – IMPLICATED IN ALMOST EVERY SEVERE OVERRUN.

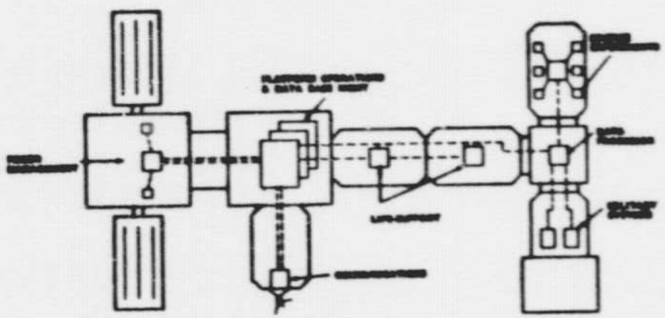
Technology Drivers

Our studies have identified many technology drivers; opportunities for investment in advanced technology that will pay off handsomely in space station benefits, economies of operation, and mission accommodations. The most important ones are summarized on the facing page.

Space Station

Technology Drivers

NASA 86-150 BOEING



NETWORK ARCHITECTURE CONCEPT

- A REVOLUTION HAS OCCURRED IN INFORMATION SYSTEMS. DISTRIBUTED PROCESSING; NETWORKING; MAINFRAME-IN-A-SHOEBOX; ARTIFICIAL INTELLIGENCE. BENEFIT FROM WHAT IS REAL WITHOUT BUYING INTO HIGH RISK.
- INTEGRATED HYDROGEN-OXYGEN SYSTEMS OFFER COMBINED ENERGY AND PROPULSION MANAGEMENT WITH GREAT FLEXIBILITY, LOW CONTAMINATION, AND ADAPTABILITY TO GROWTH.
- THE EMERGING FIELD OF ADAPTIVE CONTROL OFFERS THE OPPORTUNITY TO DESIGN A CONTROL SYSTEM THAT CAN FLY WHATEVER THE SPACE STATION EVOLVES TO, AND TO ACCOMMODATE MISSIONS WITH STRINGENT REQUIREMENTS.
- LONG-LIFE THERMAL MANAGEMENT SYSTEMS ARE ESSENTIAL TO THE PERMANENCY GOAL OF SPACE STATION.
- CONTAMINATION CONTROL AND MANAGEMENT IS ESSENTIAL TO MISSIONS USING SENSITIVE SENSORS.

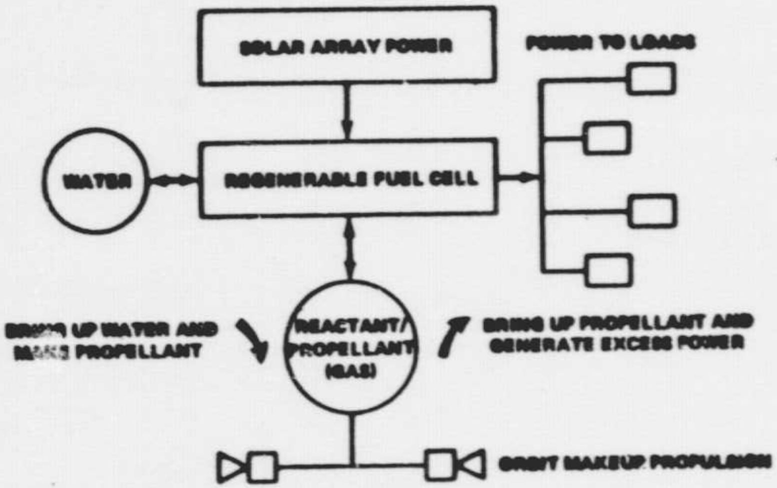
Integrate Hydrogen-Oxygen Systems

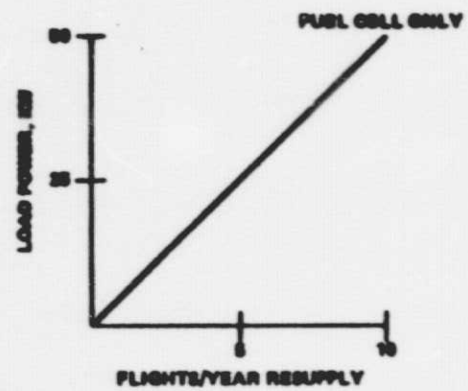
We conducted investigations into energy storage and propulsion system options under the SOC studies and on IR&D. These investigations led us to conclude that regenerable fuel cell technology should be developed for space station electrical energy storage and that this storage sytem should be integrated with the orbit makeup propulsion system for the reaons stated on the facing page. The real payoffs for this technological innovation arise from the integration benefits.

Space Station

Integrated Hydrogen-Oxygen Systems

NASA BOEING





- HEART OF THIS SYSTEM IS REGENERABLE FUEL CELL (FUEL CELL/ELECTROLYSIS) SYSTEM
- PROVIDES GREAT POWER/PROPULSION FLEXIBILITY
- LIGHTER/LESS VOLUME THAN BATTERIES; COMPETITIVE EFFICIENCY
- HIGHER ISP (360 - 380) THAN HYDRAZINE OR BI-PROP; ELECTRICALLY-HEATED HYDROGEN OPTION
- NON-TOXIC
- EASIER TO THERMAL CONTROL
- COMPATIBLE WITH ET SCAVENGING, BUT SCAVENGED PROPELLANT IS NOT "FREE"
- FUEL CELL ONLY OPTION NOT ATTRACTIVE BECAUSE OF RESUPPLY REQUIREMENT
- ET SCAVENGING BEST TIED TO OTV SPACE-BASING

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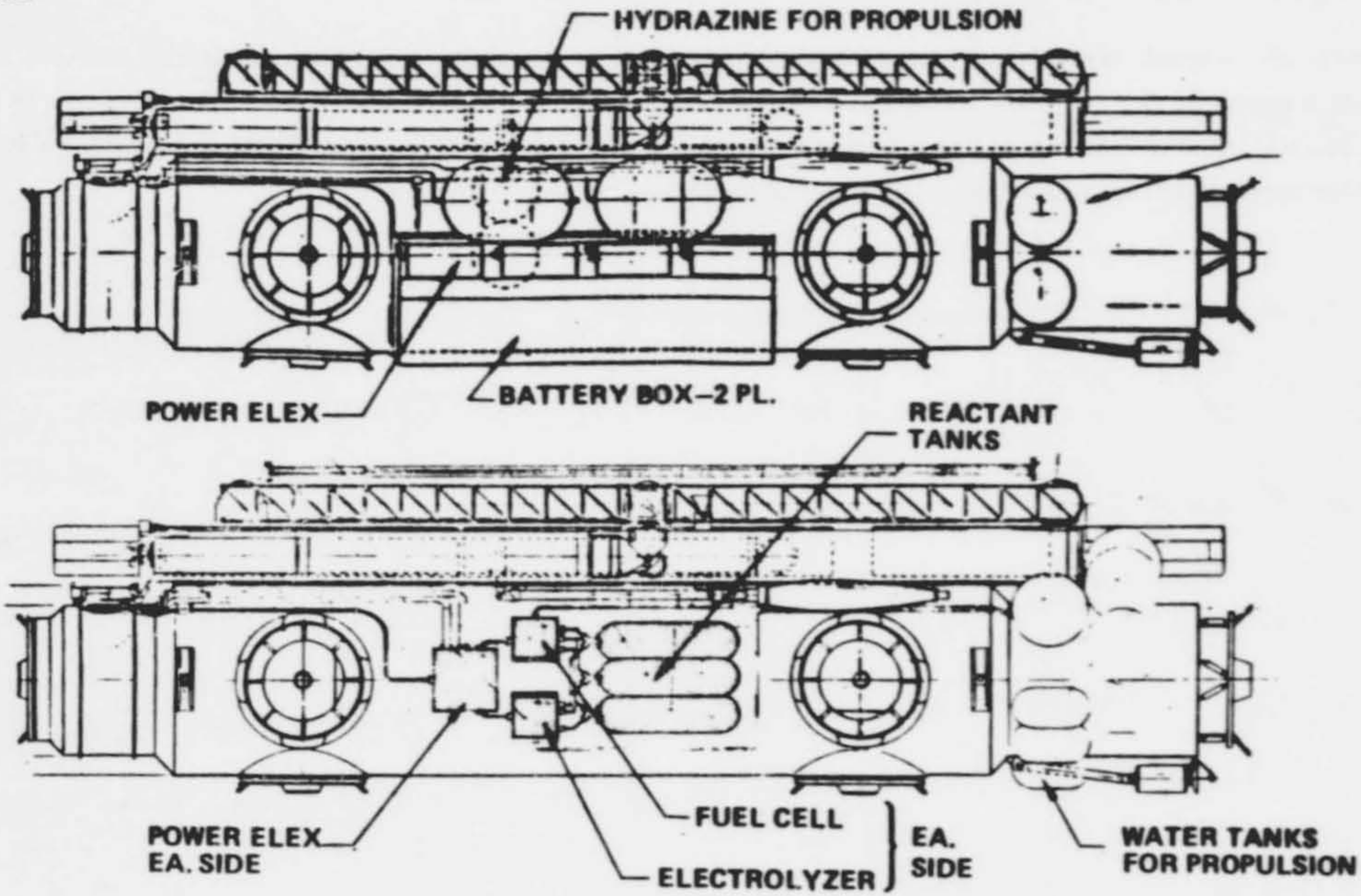
Space Station

Integrated Hydrogen Systems Equipment Installation Comparison for 20kW Load

NASA 88-086 BOEING



NOTE: CONFIGURATION OBSOLETE–FOR EQUIPMENT INSTALLATION COMPARISON ONLY

Human Factors and Man-Machine Interface

There are a great many lessons to be learned from our space flight experience in Apollo, Skylab, and Shuttle. Additional lessons may be derived from reports of Russian experiences. We are making a systematic effort to distill from the literature, astronaut interviews, and other sources, the requirements and design guidelines applicable to space station. Many of the more important requirements and rules are summarized on the facing page.

Space Station

NASA SS-160

Human Factors and Man-Machine Interface

BOEING

- CREW SOCIOLOGY/PSYCHOLOGY
  - ODD-NUMBERED CREW SIZES ARE PREFERRED
  - PROVIDE WINDOWS IN CREW PRIVATE QUARTERS AND LOUNGE AREAS
  - ENTERTAINMENT: TV, VIDEO GAMES; PROVIDE IN PRIVATE QUARTERS AND LOUNGE AREAS – TV FOR PHYSICAL CONDITIONING AREA
  - PROVIDE OPTIONS TO VARY/STRUCTURE ENVIRONMENT
  - PROVIDE TRULY PRIVATE COMMUNICATIONS CAPABILITY FOR FAMILIES
  - OFFER A LOUNGE/OBSERVATORY AREA
  - MINIMIZE SITUATIONS THAT CREATE STATUS DIFFERENCES, E.G., EVERYONE EVA QUALIFIED
  - MAXIMIZE ON-BOARD CAPABILITY TO PLAN DETAILED ACTIVITIES
  - OFFER RESEARCH OPPORTUNITIES FOR FREE TIME
  - PROVIDE "TOGETHERNESS" AND CONFERENCE TIME FOR ALL CREW TOGETHER; EAT TOGETHER AT LEAST ONCE A DAY
  - ONE DAY OFF EACH WEEK
- CREW OPERATIONS
  - CONSIDER CREW TRAINING USES OF MOCKUPS AND SIMULATORS
  - PROVIDE AMPLE DESIGN FEATURES FOR (1) SECURING THINGS LIKE PAPERS AND NOTES; (2) RESTRAINTS AND HANDHOLDS
  - INCORPORATE WARMER IN SHOWER DRESSING-ROOM
  - ASSUME THAT ANYTHING THAT CAN BE USED AS A HANDHOLD OR RESTRAINT WILL BE
  - DESIGN CONTROLS THAT INVOLVE EYE-HAND COORDINATION SO THAT OPERATOR DOESN'T HAVE TO LOOK AT HANDS
  - USE CEILING FOR STORAGE/BULLETIN BOARD
  - DON'T MISINTERPRET SKYLAB CREW CRITICISM OF MDA – MULTI-DIRECTIONALITY NOT ALL BAD
  - STORAGE: PROVIDE LOTS; USE CLEAR LABELS; PROVIDE RESTRAINTS ADJACENT
- CREW PHYSIOLOGY
  - ASSUME VARIABLE-LENGTH DUTY TOURS. CONFLICTING REPORTS ON ADAPTATION OF ZERO-g.
  - PROVIDE PHYSICAL CONDITIONING FACILITIES SO THAT PEOPLE CAN EXERCISE TOGETHER
- CREW ACCOMMODATIONS
  - PROVIDE INDEPENDENT ACCESS TO TOILET, HANDWASH AND SHOWER
  - LOCATE HYGIENE, ESPECIALLY TOILET, AWAY FROM FOOD PREPARATION
  - PROVIDE AIR CIRCULATION SO THAT HYGIENE ODORS ARE CONTROLLED
  - DESIGN TABLES, ETC., CHEST-HIGH. USE "VACUUM CHUCK" TECHNIQUE TO HOLD STUFF ON TABLES
  - DOORS TO PRIVATE QUARTERS DON'T NEED TO BE STAND-UP HEIGHT. COULD INCREASE USABLE AREA
  - MAKE AIR VENTS AND ENTERTAINMENT CONTROLS REACHABLE FROM SLEEP RESTRAINT

Artificial Intelligence

Artificial intelligence technology offers potential payoffs for space station. A summary definition of artificial intelligence and some of its applications are presented on the facing page.

Space Station

NASA

86-032

Artificial Intelligence

BOEING

THE GOAL OF ARTIFICIAL INTELLIGENCE IS THE DESIGN OF COMPUTER SYSTEMS THAT EXHIBIT THE CHARACTERISTICS THAT WE ASSOCIATE WITH INTELLIGENCE IN HUMAN BEHAVIOR—UNDERSTANDING LANGUAGE, LEARNING, REASONING, SOLVING PROBLEMS, AND SO FORTH.

SUBFIELDS	STATUS	SPACE STATION APPLICATION
COMPUTATION VISION	SYSTEMS AVAILABLE BUT MANY LIMITATIONS	
NATURAL LANGUAGE INTERPRETATION	SENTENCES; DATA BASE ACCESS, LIMITED SPEECH RECOGNITION	IMPROVED MAN-MACHINE INTERFACE; DATA BASE ACCESS
EXPERT SYSTEMS	CUSTOM-TAILORING TO SPECIFIC TASKS	SUBSYSTEMS MGMT; MISSION PLANNING; SELF-DEFENSE
PLANNING	SOME PACKAGES AVAILABLE; MUCH IN RESEARCH STAGE	MISSION PLANNING
MONITORING	RESEARCH	NATIONAL SECURITY
AUTOMATIC PROGRAMMING	RESEARCH	SOFTWARE GENERATION
LEARNING	RESEARCH	GROWTH & EVOLUTION
PLAN RECOGNITION	VERY EARLY RESEARCH	NATIONAL SECURITY

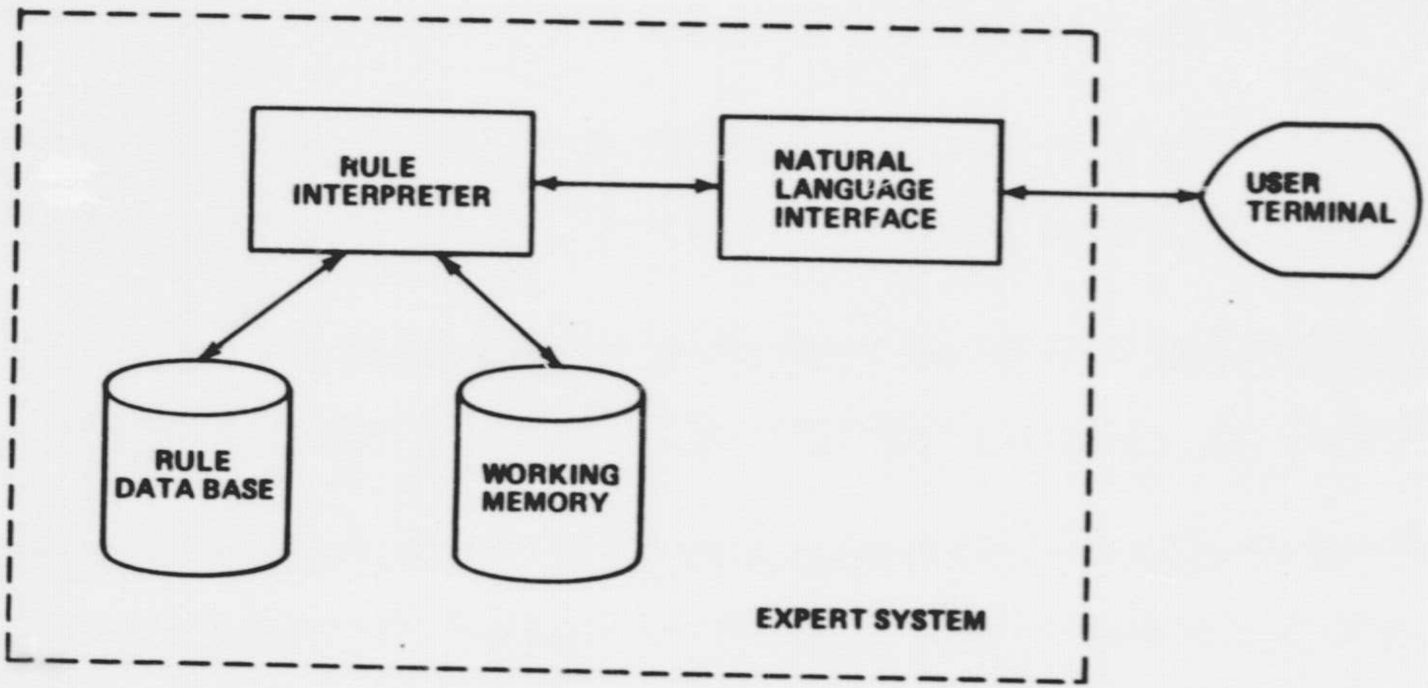
Expert Systems

One of the promising technologies is that of <u>expert systems</u>. A definition of expert systems is presented on the facing page.

Space Station

Expert System: Architecture

NASA 88-031 BOEING



Expert Systems Prerequisites for Success

Experience with devising expert systems has shown that certain factors are important to success, as summarized on the facing page.

Expert System: Prerequisites for Success

- There must be at least one human expert acknowledged to perform the task well.
- The primary source of the expert's exceptional performance must be special knowledge, judgment, and experience.
- The expert must be able to explain the special knowledge and experience and the methods used to apply them to particular problems.
- The task must have a well-bounded domain of application.

What is LISP?

In the beginnings of automation science research, a man named Turing proved mathematically that there are five and only five esential instructions that a computer must be able to execute, and that a machine able to execute these five instructions can be programmed to perform any task definable by a sequence of instructions, i.e. a program.

Modern computers are able to eaxecute hundreds to thousands of distinct instruction sets, but these extensive menus of instructions are for the convenience of the programmer; they are not necessary in a theoretical sense. Similarly, artificial intelligence languages and machine architectures are not required in a theoretical sense, but they greatly speed up and simplify programming and executing artificial intelligence types of tasks.

What is LISP?

- LISP is a programming language designed to facilitate symbolic manipulation as opposed to numeric manipulation.
- The key requirements for a LISP architecture are the following:
  - Large virtual address space
  - Ability to process symbolic information
- LISP machines typically incorporate the following hardware features:
  - Stacks
  - Tagged memory elements
  - Extensive use of microcoding
  - Efficient multi-level indirect addressing

Speculative Office Building Architecture

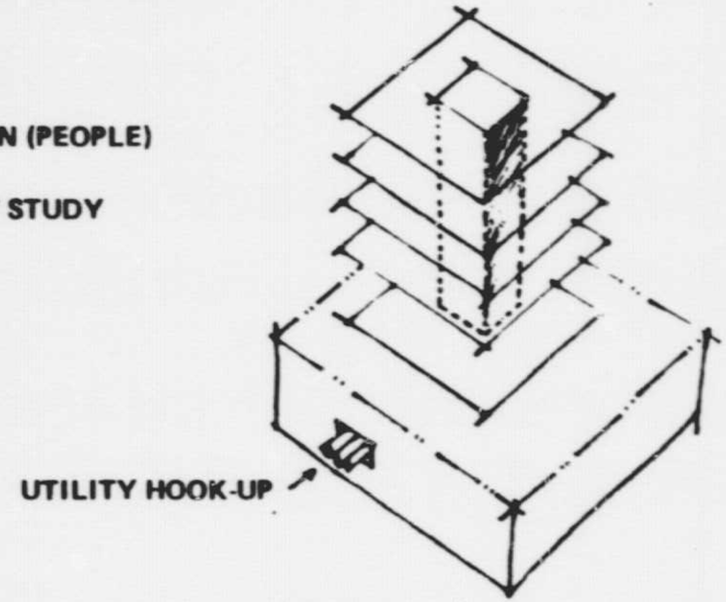
Our search for architectural principles applicable to space station led us, among other avenues, to a comparison with conventional business architectural practice.

Space Station

Speculative Office Building Architecture

NASA SS 100 BOEING

- CORE FUNCTIONS
  - MECHANICAL/ELECTRICAL
  - HVAC
  - HYGIENE
  - STRUCTURE
  - PHONE
  - CIRCULATION (PEOPLE)
- PLANNING
  - FEASIBILITY STUDY
  - PRE-LEASE
  - MARKETING



- ARCHITECTURE
  - PHYSICAL BOUNDARIES (PROPERTY LINES)
  - ZONING
    - HEIGHT
    - USE
    - SETBACK
  - FIRE ZONE
  - SAFETY CODE
  - BUILDING CODE
  - SPECIAL USE (HANDICAPPED)
  - BUDGET
  - LIFE CYCLE COST
  - APPEAL (PARTICULAR CLIENTELE)
  - STORAGE/PARKING
  - ECONOMIES OF SCALE

Space Station Architecture

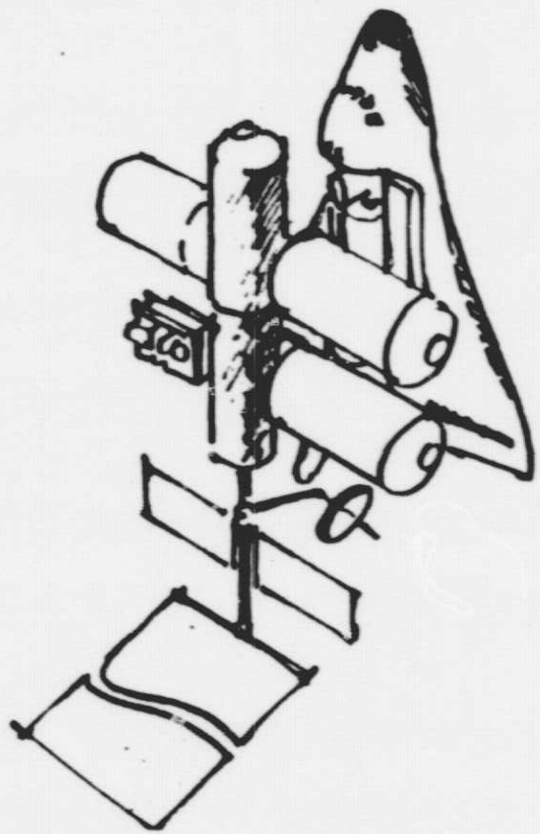
The comparison between speculative building architectural principles and those applicable to a space station is striking!

Space Station

Space Station Architecture

NASA SS 179 BOEING

- CORE FUNCTIONS
  - POWER AND THERMAL CONTROL
  - ECLS
  - HYGIENE
  - STRUCTURE (STRONG BACK)
  - DATA LINK/COMM.
  - CIRCULATION (PASSAGEWAY)
- PLANNING
  - FEASIBILITY STUDY
  - PRE-LEASE
  - MARKETING



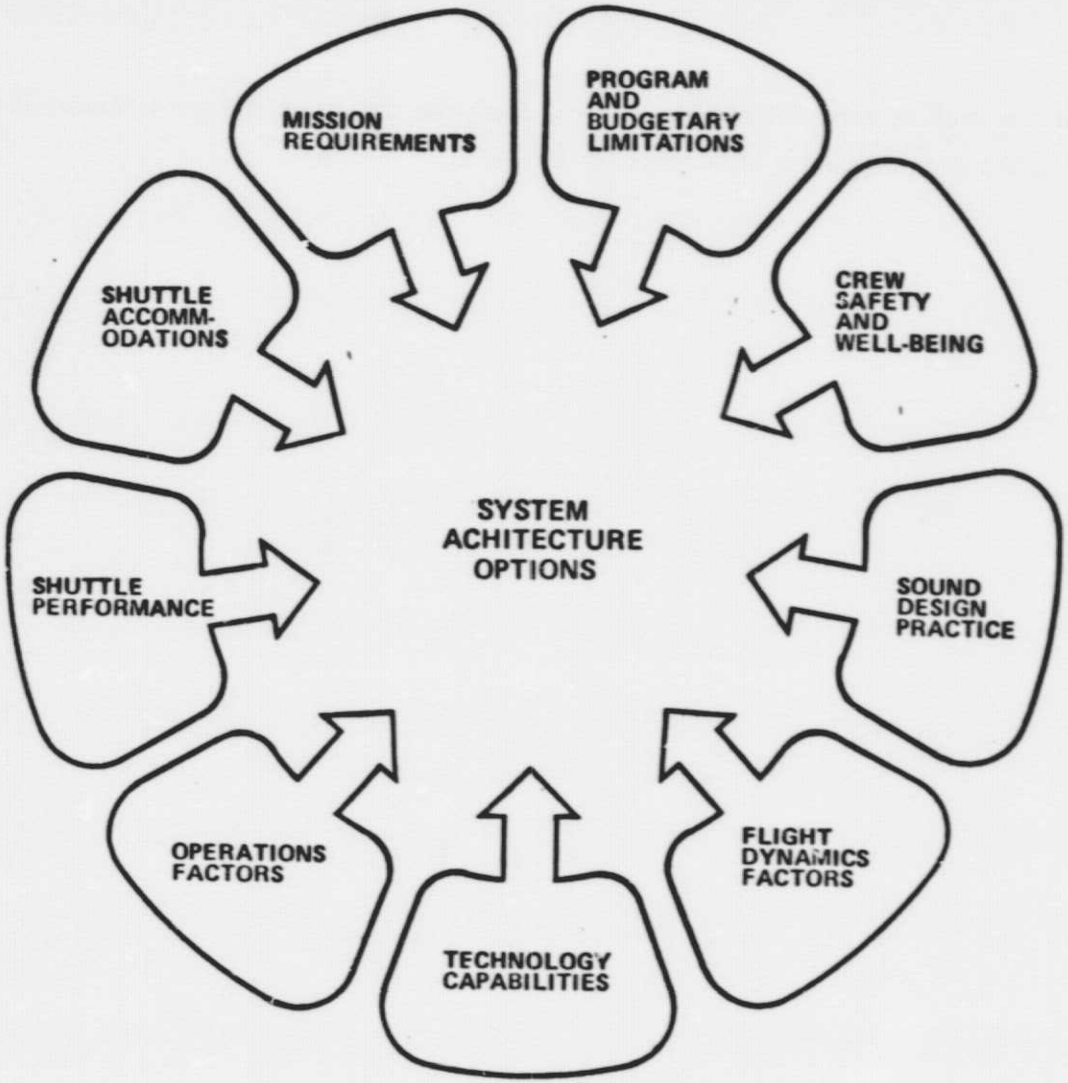
- ARCHITECTURE
  - DELIVERY ENVELOPE
  - ZONING
    - C.G.
    - PLUME IMPINGEMENT
    - ARRAY SHADOW
  - FIRE REGULATIONS
  - SAFETY REGULATIONS
  - CONSTRUCTION SPECS
    - MILITARY
    - CIVIL
  - SPECIAL USE (EVA)
  - BUDGET
  - LIFE CYCLE COST
  - APPLICATION
    - EXPERIMENT
    - OPERATION
  - STORAGE/PARKING
  - ECONOMIES OF SCALE

Architectural Constraints

Mission requirements are only one of many needs and constraints applicable to the definition of a space station architecture. Other important ones are symbolized on the facing page.

System Architecture Contstraints

SS 186



Point-of-Departure Architecture Guidelines

We have initiated our architecture definition activity, using the design guidelines summaried on the next two pages. Along with rules, these pages give rationales or sources for the rules.

Space Station

Point of Departure Architecture

NASA SS 007 BOEING

RULE	RATIONALE
1. LIMITED CLASS ARCHITECTURE	CONFORMS TO NASA GROUND RULES
2. 5 CREW IN 2 EAST LAUNCH MODULES (50K)	NASA INPUT – "NEEDS TO BE BIGGER THAN SALYUT, BUT NOT A BUDGET-BUSTER"
3. MODULES TO BE DESIGNED AS ONE WORK MODULE AND ONE LIVING MODULE	AVOID DISTURBING OFF-DUTY OR SLEEPING CREWMEN
4. DIFFERENCES IN MODULES TO BE CONFINED TO INTERNAL PARTITIONS AND EQUIPMENT LOCATION	MAINTAIN COMMONALITY WHERE IT COUNTS – BASIC SUBSYSTEMS AND STRUCTURES
5. PROVIDE PRIVATE QUARTERS SLEEP RESTRAINT WRITING DESK TERMINAL/VIDEO ADJUSTABLE VENT-REACH FROM SLEEP RESTRAINT PERSONAL LOCKER	BASED ON ASTRONAUT INTERVIEWS – TRY FOR 4 X 5 FLOOR SPACE
6. EAST LAUNCH MODULES DIVISIBLE TO BECOME 25K LB MODULES FOR POLAR LAUNCH. BERTHING JOINT FOR POLAR, BUT FACTORY SPLICE FOR EAST.	SHUTTLE CAPABILITY LIMITS AND POTENTIAL NEED TO ESTABLISH A SMALL POLAR STATION
7. WORK MODULE TO SERVE AS "SAFE HAVEN." ALSO WITH LOGISTICS MODULE TO OPERATE AS INTERIM 2-MAN STATION A LA SALYUT (NO PVT. QRTS.)	SAFETY RULES; ALLOW MANNING OF INITIAL STATION
8. SOLAR ARRAY CONFIGURATION ADAPTABLE TO ANY LOW ORBIT – 2 DEG. OF FREEDOM AS NEEDED TO ALLOW EARTH ORIENTATION.	MISSION FLEXIBILITY

Space Station

Point of Departure Architecture

NASA — BOEING

RULE	RATIONALE
9. MAST LENGTH LIMITED TO SINGLE HINGE	SIMPLICITY – CAN ACCEPT SOME SHADOWING
10. EXTERNAL AIRLOCKS	REASONS FOR SELECTING THIS ON SOC STILL VALID
11. BERTHING PORTS:	
2 – SHUTTLE (DOCKING) 2 – RESUPPLY MODULE	ONE EACH END TO SIMPLIFY EXCHANGE
2 – TMS * 2 – LAB MODULES	EXPERIMENTS LAB AND DIAGNOSTICS LAB
4 – EXPERIMENT PALLETS * 2 – EARTH VIEWING 2 – SKY VIEWING 2 TO 4 – GROWTH MODULES 1 – SPARE	
12. INCLUDE RMS ON INITIAL (WORK) MODULE	ASSIST IN ASSEMBLY AND MISSION OPERATIONS
13. HIGH-GAIN ANTENNAS ON MASTS WITH VIEW OF GEO	TDRS COMMUNICATIONS
14. PROVIDE BOTH THRUSTER AND CMG ATTITUDE CONTROL OPTIONS	FOR ADAPTABILITY TO EARTH AND INERTIAL ORIENTATION
15. RESUPPLY MODULE ACCOMMODATIONS:	ASSUMES INTEGRATED $O_2 \cdot H_2$
FOOD, ETC. RESUPPLY INSIDE TOILETS EMERGENCY EC/LS – 21d. WATER FOR ORBIT MAKEUP AND EC/LS MAKEUP NO SUIT WATER SHUTTLE CRYOTANK KIT OPTIONAL	
16. INTEGRATED $O_2 \cdot H_2$ SYSTEM	TRADEOFF SHOWS PREFERRED OVER BATTERIES

* DON'T NEED PRESSURIZED HATCHWAY

CANCELLATION OF NASA RFP's

NASA went to great lengths to promote opportunities for space science missions in the space shuttle program during the 1970's. As a consequence, the scientific community was bouyed up by visions of numerous flight opportunities. Cost overruns in the Space Shuttle program that depleted support for space science, and extensive delays that required much research to enter a prolonged holding pattern hurt the enthusiasm of the community. This cancellation of Spacelab and LDEF payload RFPs has generated a strong feeling of caution among the space science research community. NASA's reputation for following through on mission opportunities was tarnished by this series of events. We believe the present approach of gathering information in the user community in advance of designing a Space Station will alleviate much of the concern that remains in the community today. It is equally as important to present a realistic program schedule so that experienced principal investigators can properly assess their opportunities for participation. Scientists nearing retirement are not motivated to respond to an opportunity that is 10 years or more away. We have to reach a larger proportion of the younger scientists who have much less experience with space operations and motivate them to share their new ideas for research programs.

NASA
National Aeronautics and Space Administration
Washington, D.C. 20546

Reply to Attn of: SL-4

16 October 1981

Amendment 4

CANCELLATION OF REQUESTS FOR PROPOSALS
Concerning
Announcement of Opportunity
AO-OSS-2-78

Physics Astronomy and Planetary Science
Spacelab and LDEF Payloads

Originally Issued June 16, 1978
Amendment 1 May 22, 1979
Amendment 2 June 1, 1979
Amendment 3 June 16, 1980

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Dear Colleague:

Due to the lack of funds in the near-term budgets for Spacelab and LDEF instrument development, the request for new proposals under AO-OSS-2-78 (as amended) is cancelled, and the AO is closed. NASA remains actively interested in the Spacelab and LDEF scientific opportunity, and intends to request proposals in the future when the financial situation becomes clear. The AO is being closed rather than extended because it is rapidly becoming outdated. During the long interval since the original announcement (June 1978), we have learned new things about using the Shuttle and Spacelab. These valuable learning experiances are leading to new procedures and conditions for carrying out such developments, and for using and reusing instruments. This new information will be incorporated into future announcements which will be released when we have a more secure understanding of the future of this program and are prepared to proceed on a realistic basis.

Sincerely,

Andrew J. Stofan
Acting Associate Administrator
for Space Science

Making the Space Station User Friendly

Some suggestions for making the system user friendly are summarized on the facing page, in technical, operational, and institutional categories. Many of these were touched on earlier in the briefing.

An example is in attention to software languages made available to experimenters. The station systems themselves are likely to employ a modern, professional, high-capability language like ADA. Science users, however, may be more comfortable with an older language like Fortran, Pascal, or Basic. These options should be offered to the science users.

Space Station

Making the System User Friendly

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- Technical
  - Low contamination; environment control flexibility
  - Adequate services
    - Power
    - Thermal control
    - Ports and workspace
    - Data, computation, languages
- Operational
  - Frequent access
  - Visiting scientists
- Institutional
  - Minimum bureacracy
  - Turnkey capability for those who need it
  - Short time scales – get on, get results, get off
  - User charge structure
  - Proprietary protection

User Charge First Cut

We have made an initial estimate of user charge formulas to obtain an idea of costs to users. Derivation of the charge formula is summarized on the facing page. Cost figures are based on earlier studies, but are believed representative. Note that the user charges amortize DDT&E as well as purchase costs. Even so, the charges against user mission appear modest. An example for a microgravity processing opeation is summarized on the following page, and exhibits roughly a factor of ten savings over use of the shuttle.

C-3

Space Station

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User Charge Rough Cut

BOEING

SS-164

ASSUMPTIONS:

- 5-MAN STATION = $2.5B, 1982 DOLLARS, NO MISSION EQUIPMENT COSTS
- INVESTMENT AMORTIZED IN 10 YEARS
- TRANSPORTATION CHARGES FOR MISSION EQUIPMENT NOT INCLUDED

USER ITEM	COSTS INCLUDED	COST SHARE	BASIS	CHARGE
ELECTRIC POWER	ALL ELECTRIC POWER ALL THERMAL CONTROL ALL PROPULSION	31%	25 KW	$8800/KW-DAY + TRANSPORT CHARGE IF EXTRA REACTANT
CREW TIME	1/3 STRUCTURE ALL DATA MANAGEMENT AND COMM ALL CREW EQUIPMENT AND EC/LS	55%	5 CREW	$77,000 PER MAN-DAY
BERTHING PORTS	1/2 STRUCTURE	5%	5 USABLE PORTS	$7000 PER PORT-DAY
INTERNAL VOLUME	1/6 STRUCTURE	9%	7000 FT^3	$10 PER FT^3-DAY

EXAMPLE: 90-DAY SERVICE MISSION USES 1 PORT, 2 KW, AND 1 MAN-DAY PER WEEK. USER CHARGE = $3.2 MILLION

Space Station

Space Station vs Shuttle for GaAs Growth

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SS-182

SHUTTLE

ASSUMPTIONS

- POWER LIMITED $\approx$1600 kwh IN 6 DAYS $\approx$12.8 kg CRYSTAL
- FLY ON MISSION THAT DELIVERS A PRIMARY PAYLOAD
- PAY FOR 6 EXTRA DAYS ON ORBIT
  300 kg FURNACE
- ONE MISSION EACH 90 DAYS

COSTS

• FURNACE TRANSPORT CHARGE	$0.75M
• REACTANT TRANSPORT CHARGE	$1.9M
• ON-ORBIT TIME @ $1M/DAY	$6 M
• $250K FOR FURNACE WRITEOFF	$0.25M
	$8.9M FOR 12.8 kg

COST – $695/gm

SPACE STATION

ASSUMPTIONS

- PRODUCTION 100 kg EVERY 90 DAYS
- 150-HOUR FURNACE RUNS, 14 EACH 90 DAYS
- 50 CUBIC FT
- 500 kg TRANSPORT CHARGE FOR 100 kg CRYSTAL
- 2 MAN-DAYS PER PROCESS RUN

COSTS

• TRANSPORT CHARGE	$1.33M
• VOLUME CHARGE	$45K
• POWER CHARGE (6 kw AVERAGE)	$4.86M
• 28 MAN-DAYS	$2.156M
• FURNACE WRITEOFF	$0.25M
	$8.641M

COST – $86.41/gm

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